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SHUTTLE/AGENA STUDY

FINAL REPORT

PREPARED FOR
THE NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER • HOUSTON, TEXAS

CONTRACT NAS9-11949

LMSC
SPACE SYSTEMS
DIVISION

VOLUME II

TECHNICAL REPORT

PART ONE:

PROGRAM REQUIREMENTS, CONCLUSIONS, RECOMMENDATIONS

LOCKHEED MISSILES & SPACE COMPANY, INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

25 February 1972

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Vol II, Part 1

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TECHNICAL REPORT

Part One
- PROGRAM REQUIREMENTS
- CONCLUSIONS
- RECOMMENDATIONS

Contract NAS9-11949
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Prepared for the
National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas

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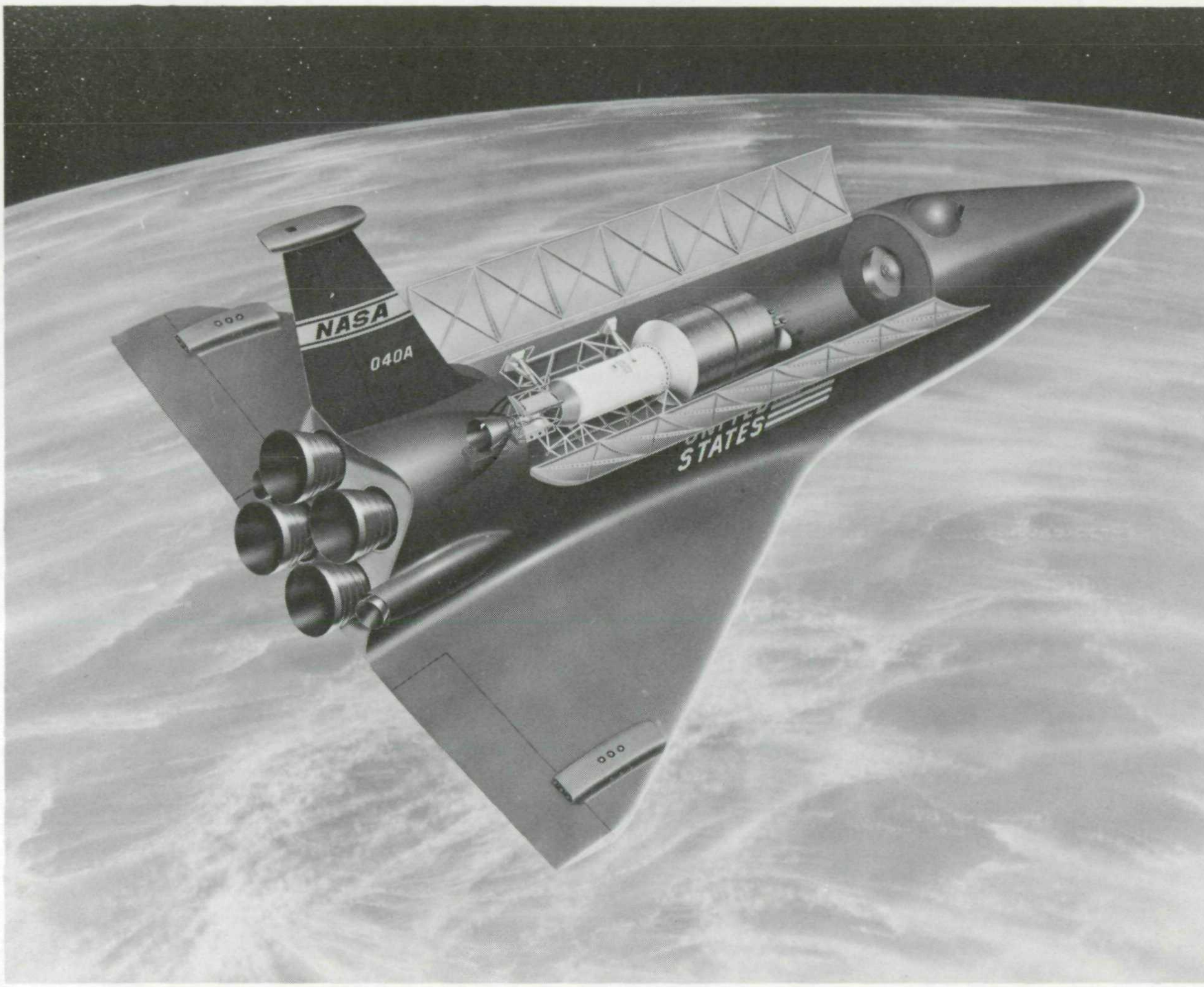
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FOREWORD

This final report has been prepared for the National Aeronautics and Space Administration's Manned Spacecraft Center, Houston, Texas, under Contract NAS9-11949. Volumes I and II are submitted as DRL line items 6 and 7, as specified in DRD MA-012T and MA-129T of the subject contract. Although not contractually required, supplemental data on the Ascent Agena and existing flight equipment are also submitted.

In compliance with customer guidelines regarding page limitations, the report is bound in separate books as follows:

• Volume I	Executive Summary
• Volume II, Part One	Program Requirements, Conclusions, Recommendations
• Volume II, Part Two	Agena Tug Configurations, Shuttle/ Agena Interface, Performance, Safety, Cost
• Volume II, Part Three	Preliminary Test Plans
• Annex A	Ascent Agena Configuration
• Annex B	Catalog of Existing Flight Equipment
• Annex C	Space Shuttle Candidate Insulator/ Propellant Compatibility Test Program

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Section 1
INTRODUCTION

The Shuttle/Agena Study was conducted by Lockheed Missiles & Space Company, Inc., for the National Aeronautics and Space Administration Manned Spacecraft Center under Contract NAS9-11949. It represents a comprehensive evaluation to determine the compatibility of the Agena with the Space Transportation System for use as an expendable third stage to the space shuttle. More specifically, the Agena was considered for those missions requiring additional propulsion capability beyond that used for low earth orbit. Conducted over an 8-month period, the study defines the interface requirements imposed on both the Agena and the shuttle system and identifies those areas where the Agena must be improved or modified to satisfy mission requirements.

1.1 OBJECTIVES AND SCOPE

The primary objective of the study was to determine the operational characteristics and significant interface areas of an earth-storable upper stage that is capable of extended orbital life and of being deployed and launched from shuttle orbit. To provide a realistic basis for the study, the Ascent Agena space propulsion vehicle was used as the design starting point. However, because of the general nature of the analyses, data resulting from the study are applicable to other earth-storable stages as well

1.1.1 Purpose and Objectives

The main emphasis of the study was directed toward:

- Defining the overall system and its operational characteristics
- Outlining possible problem areas and indicating feasible solutions
- Delineating interface requirements
- Defining a baseline configuration, its performance, and its costs

The configuration, performance, and cost data for an evolutionary vehicle were also examined on the basis of probable Agena improvements which might be incorporated prior to the shuttle Initial Operational Capability (IOC).

Specific objectives of the study were to:

- Compare the Ascent Agena operational characteristics and interface requirements with those of the Space Transportation System
- Identify requirements for change and/or modification to the Agena vehicle, GSE, checkout and launch control equipment, software, and other support equipment
- Evaluate Agena/space shuttle interface and delineate requirements
- Establish a baseline Agena tug configuration and interface design
- Identify possible evolutionary vehicle configurations and determine potential impact on shuttle operations
- Determine the performance capability of the baseline and evolutionary vehicles for specified reference missions
- Develop integrated program costs associated with the baseline and evolutionary vehicle designs

1.1.2 Guidelines and Constraints

The study was conducted within the guidelines and constraints set down by the following documents:

- "Exhibit A – Work Statement for the Study of Compatibility of the Agena Space Propulsion Stage With the Earth Orbit Shuttle," NASA-MSC, Contract NAS 9-11949
- Space Shuttle User's Guide, Edition 1, NASA-MSC, 21 June 1971
- Preliminary Payload/Orbiter Interface Requirements for Space Shuttle, NASA, MSC, 26 January 1971
- Space Shuttle Phase B Final Report, Volume II, NAR, 26 March 1971

In addition to the above, information contained in the following documents provided added insight into potential Agena tug applications and missions:

- Research Application Module Interface Definition, RAM RFP, January 1971
- Statement of Work for Agena Applications, NASA, MSC, 1 March 1971
- Preliminary DOD Shuttle System Requirements, Aerospace Corp, 17 May 1971
- OOS/Shuttle Interface Trade Study Description, Aerospace Corp, 7 June 1971

A summary of the principal guidelines and constraints follows:

- The Agena vehicle was to be configured for use as an expendable upper stage of the Space Transportation System to transport and deliver payloads from the shuttle orbit to the desired spacecraft orbit and position. Major study effort was directed to the basic characteristics of the present Ascent Agena as described in Annex A with only those modifications required to make it compatible with the Space Transportation System.
- For this study, the payloads were considered to be separable spacecraft which operate independently of the Agena; however, provisions for integrated, nonseparable payloads were also considered with respect to certain subsystems, such as power supply and telemetry.
- The Agena and the spacecraft will be carried to the shuttle orbit within the shuttle cargo bay. The Agena is to be considered only as cargo during the ascent flight.
- The Agena and the spacecraft will be deployed at the nominal 100-nm shuttle orbit and at the inclination corresponding to the spacecraft orbit or at the inclination which will permit the most economical spacecraft injection.
- Shuttle ascent trajectory will be characterized by a 50 x 100 nm transfer orbit with circularization at the 100-nm apogee. Flight time from launch to final orbit injection is approximately 45 min.
- After injection into shuttle orbit, the Agena may remain within the shuttle cargo bay for a period of up to 3 hr. Nominally, it is assumed that the Agena/spacecraft checkout and deployment will take place during the first orbital pass.
- For nominal conditions following deployment by the orbiter, any required monitoring of telemetry data or command and control of the Agena vehicle will be performed by available ground stations. As a design goal, the orbiter should have the option of controlling and monitoring the Agena.
- The maximum Agena/spacecraft weight is 65,000 lb, corresponding to the structural design load of the orbiter. The maximum nominal cargo weight for landing is 40,000 lb; however, for a mission-abort condition, a higher landing weight may be acceptable. (This condition applies only to an abort condition for the Agena missions.)
- Three basic missions were to be considered to identify mission- and spacecraft-peculiar requirements:
  - I – A geosynchronous mission (equatorial orbit) with the Agena providing all propulsion beyond deployment from the orbiter
  - II – An unmanned planetary injection mission allowing for coast capability to provide a reasonable launch window
  - III – A low-earth-orbit mission requiring a plane and altitude change, active stabilization in a circular orbit for up to 30 days, followed by return and rendezvous with an orbiter.
- Use of the Agena tug was not to jeopardize the safety of the shuttle crew or passengers.

1.1.3 Technical Considerations

In the selection of systems and components for the Agena or the modification of current designs to meet the requirements of the Agena tug, state-of-the-art technology was to be employed. Advanced technology was to be considered only where clear evidence existed that the technology would be available in time to meet the schedule needs. For evolutionary tug designs, only those Agena modifications and improvements which could be expected through normal evolution prior to the shuttle Initial Operational Capability were to be considered.

To maintain maximum flexibility for both Agena and orbiter mission application, design commonality between missions was to be stressed. To the maximum extent possible, Agena interfaces with both the shuttle and spacecraft should be unaffected by spacecraft configuration or mission characteristics.

Wherever possible, off-the-shelf rather than new designs were to be selected for the Agena tug. Fortunately, a broad selection of system designs, that have been developed for the Agena or could be adapted for Agena use from designs used on related vehicles, is available at LMSC. A catalog of existing flight systems is included as Annex B.

1.2 STUDY APPROACH

As required by the Statement of Work, the study was divided into four major tasks:

- Task 1 – Stage Operational Characteristics and Interfaces
- Task 2 – Baseline Configuration Design
- Task 3 – Performance Capability
- Task 4 – Cost Analysis

A fifth task, documentation and reviews, was added.

1.2.1 Study Plan

The study plan for the technical effort is shown in Fig. 1-1, in which the four major tasks are broken into subtasks to better illustrate the interdependence of study elements. The study was generally performed as indicated in this diagram. However, because of interactions among the various tasks, some adjustments were made in the sequence of the work as the study progressed.

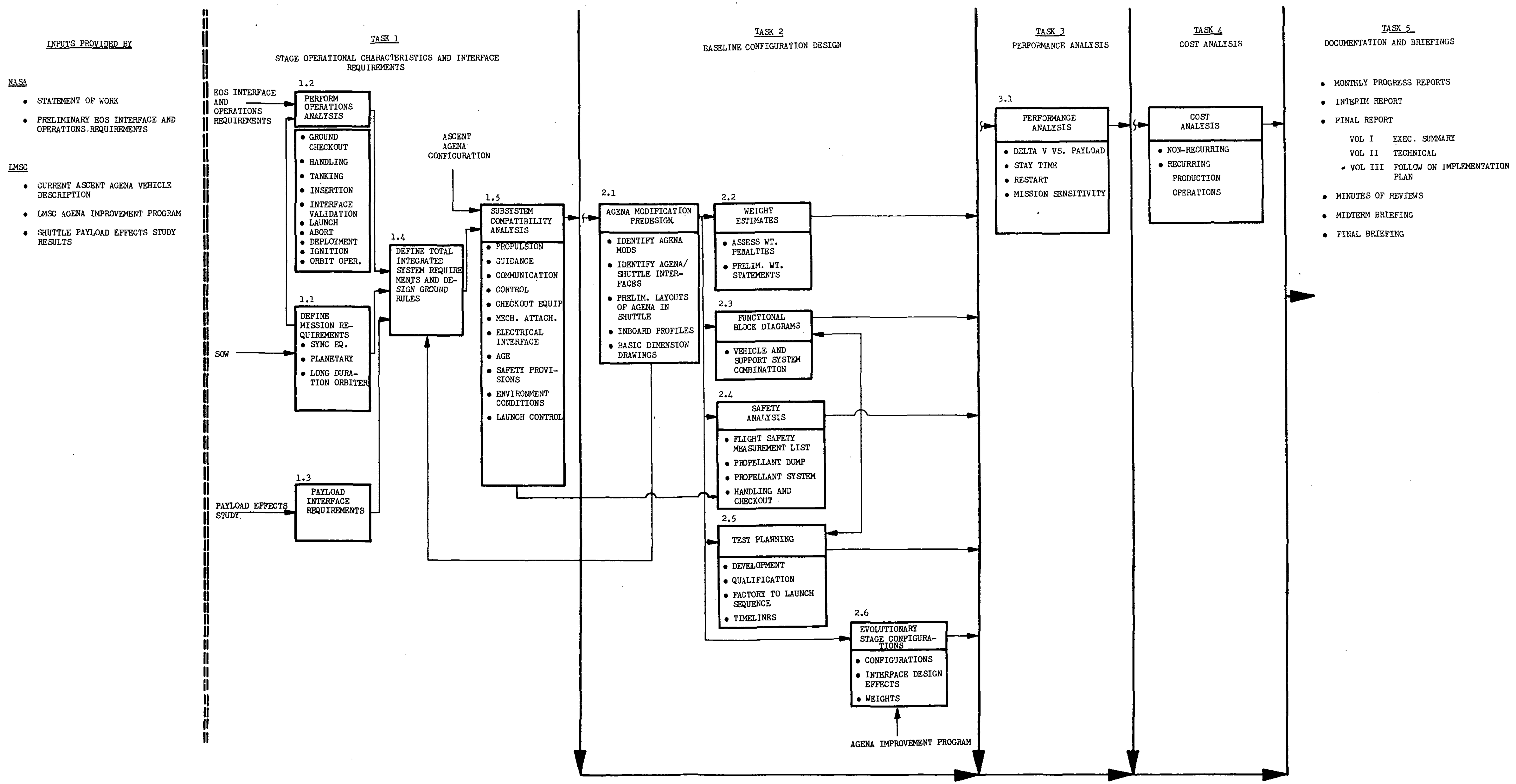

Fig. 1-1 Study Flow Diagram

Task 1: STAGE OPERATIONAL CHARACTERISTICS AND INTERFACES

This task included five activity areas, as shown in Fig. 1-1: (1) Mission Requirements Definition, (2) Operations Analysis, (3) Payload Interface Requirements Definition, (4) Preliminary System Definition, and (5) Subsystem Modification Requirements. An outline of the approach planned for each area follows.

Subtask 1.1: Mission Requirements

A brief analysis of the three basis mission modes defined by the work statement was conducted in sufficient detail to define significant mission parameters and requirements. Velocity requirements, number of engine burns, burn durations, passive coast spans, plane change, and altitude change were estimated. A preliminary sequence of events was established for each mission and significant mission requirements tabulated.

Subtask 1.2: Operations Analysis

An operations analysis was then performed to establish in a preliminary manner the basic shuttle operational sequence and constraints that dictate the modified Agena configuration and Agena/shuttle interface. In this analysis, the total sequence from factory checkout through all launch base activities, launch, ascent, deployment, Agena flight initiation, and orbit operations, was considered. Special attention was devoted to the manned shuttle environment and its impact on the safety aspects of the overall operational sequence.

Subtask 1.3: Payload Interface Requirements Definition

Some consideration had to be given to the effect a payload would have on the Agena configuration and on the operational sequence. To accomplish this, general definition of the payload interface was obtained from the "Payload Effects Study" currently underway at LMSC under a NASA/Headquarters contract. In general, however, the payload was considered to be a separable spacecraft which will operate independently of the Agena.

Subtask 1.4: Preliminary System Requirements Definition

A preliminary set of system requirements based on the results of the three previous Task 1 areas was developed. This definition included the total system: shuttle, Agena vehicle, software, support equipment, etc. The overall operational sequences were considered for each mission mode to assure that all supporting subsystems and interface effects had been adequately treated.

Subtask 1.5 Subsystem Modification Requirements

With the preliminary requirements defined, the current Agena configuration and performance capability were evaluated. Each hardware item, operational sequence, and environmental capability that required modification was identified for use in Task 2. The proposed Agena baseline configuration and performance capability were reviewed with the COR.

Task 2: BASELINE CONFIGURATION DESIGN

The preliminary baseline configuration definition effort involved the development of designs to satisfy the design requirements and shuttle interface criteria identified in Task 1. In addition, the effects of adopting a possible evolutionary Agena configuration and performance improvements were investigated.

Subtask 2.1: Agena Modification Preliminary Design

Design approaches based on the already established and existing Agena configuration which satisfied the Agena modification requirements from Task 1 were developed. Mission-peculiar modifications, as a function of the three basic mission modes, were identified.

The modified Agena/shuttle interface was examined to permit design and performance tradeoff evaluations on both the Agena modifications and the shuttle interfaces. Environmental conditions, margins and contingencies, configuration constraints, and safety and abort aspects were included in this evaluation.

Informal reviews, including assessment of comparative performance, weight penalties, gross costs, and safety/abort aspects among the promising approaches, were conducted. These reviews established the degree of compliance with the requirements established in Task 1 and with the shuttle and Agena operating characteristics, environment, and constraints.

Final configuration layouts of the modified Agena and interfaces as installed in the shuttle cargo bay were completed, together with inboard profiles and basic dimension drawings.

Subtask 2.2: Weight Estimates

A weight statement was prepared for the final modified Agena configuration and the required interface support equipment. This weight statement was detailed to the major functional component level (level 7) for the Agena baseline configuration and to the major assembly level (level 6) for the interface equipment.

Subtask 2.3: Functional Block Diagrams

Functional block diagrams were prepared depicting the vehicle and the interfaces with the support systems and shuttle. These diagrams included mechanical, electrical, and operational relationships.

Subtask 2.4: Safety Analysis

A preliminary safety/hazard analysis was performed to identify problem areas. Special problems relating to the use of an earth-storable-propellant upper stage in the shuttle were reviewed to define significant features that require special handling. Design approaches and operational sequences were defined that provide adequate protection to the shuttle and crew. Special emphasis was given to possible propellant contamination in the shuttle cargo bay, techniques for detecting potential or actual propellant system leaks, recommended propellant disposition in the event of an abort, and propellant handling during loading. Other potentially critical safety items such as pressure vessels, electromagnetic interference, etc., were also considered and a list of measurements necessary for flight safety was compiled.

Subtask 2.5: Development and Test Plans

Proposed development and qualification test plans that include provisions for all testing necessary to aid in confirmation of the modified Agena configuration were prepared. All necessary testing from the major component level to complete systems-level checks were included.

It is anticipated that many existing Agena flight-qualified components will be utilized; no requalification should be necessary for these units. A possible exception would be any NASA "man-rating" requirements or testing made necessary because of new environmental conditions resulting from shuttle interface effects.

The operations events involved in the Agena factory-to-launch sequence were identified, integrated, and assembled into a sequence of events including:

- Factory acceptance testing at major levels, including a final complete systems-level vehicle check just prior to shipment to the launch base
- Shipment to the launch base
- Prelaunch preparations up to commitment to flight

This preliminary proposed sequence plan was examined for cost-effective elements in terms of cost in dollars and cost in schedule time. Sequence timelines were prepared and integrated with already-established Agena vehicle schedule spans and typical shuttle vehicle sequence timelines.

Subtask 2.6: Evolutionary Stage Configurations

The Agena space tug guidelines are also applicable to the evolutionary stage. Technology improvements defined by the LMSC Agena Long-Range Improvement Program were reviewed, and planned improvements in the engine and propellant tankage areas that are nearly certain to be flight-proven prior to the first space shuttle flight were selected. The guidance, attitude control, power, and communications sybsystems previously defined for the Agena space tug are also used in the evolutionary stage design.

From this conceptual configuration, preliminary estimates of the effect on the already-established baseline Agena/shuttle interface, including weight and cost, were made.

Task 3: PERFORMANCE ANALYSIS

The overall performance capability of the modified Agena configurations derived in Task 2 when operated with the shuttle as a launch and orbit injection system were determined.

The key performance criterion is payload-on-orbit capability, which was determined and documented in terms of characteristics of each mission model. Improvements in performance offered by incorporation of Agena evolutionary changes were also determined.

Task 4: COST ANALYSIS

A full-scale cost analysis of the baseline configuration and the selected evolutionary vehicle concept, their operational modes, and their interface requirements was conducted. Costs associated with all phases of Agena evolution for the shuttle/Agena application, including nonrecurring (development phase), recurring production (investment phase), and recurring operations (mission phase) costs were considered.

Hardware costs were derived primarily from the detailed Agena vehicle cost estimates that Lockheed has prepared, including the Gemini configuration (multiple start, docking capability), Ascent Agena configurations (two or three starts, boost capability only), and various spacecraft Agena configurations (three-axis stabilized, extended life, integrated payload). For hardware peculiar to the baseline Agena configuration or to the space shuttle/Agena interface, costs were estimated on the basis of costs of analogous hardware from other programs. Recurring operations costs were derived primarily from current Agena launch and mission operations costs; added tasks imposed by the shuttle/Agena mode of operation were estimated on the basis of the predicted time and manpower required to perform them. In all of the recurring cost analyses, extensive use was made of the detailed data bank Lockheed has developed on Agena costs.

Nonrecurring costs predicated on preliminary development plans and schedules for required Agena modifications and for new development items such as interface equipment were estimated. Test hardware was costed on the basis of the recurring unit costs of the appropriate subsystems and components. Test operations were estimated on the basis of projected average manpower loadings for the indicated schedule spans. Engineering design, analysis, systems integration, and program management were also estimated on a time-and-manpower basis.

1.2.2 Principal Contributors

Principal contributors to the study and the field of their specialties were as follows:

Program Manager	M. M. Herardian
Chief Systems Engineer	W. K. Carter
Systems Analysis and Integration	G. A. Hafstad
Structural Design	H. E. Johnson, E. F. Cavey
Performance and Mission Analysis	J. P. Skratt
Safety and Reliability	J. E. Piper
Test Plans	F. G. Blakey, E. C. Railey
Cost Analysis	C. V. Hopkins
Ascent Agena Configuration	J. B. Taffe, K. Urbach
Propulsion	J. Zichwic
Guidance	D. A. Wilson, C. Gabriel
Power	E. Nelson, M. Gandel
Communications	D. Millet
Launch Operations Analysis	K. Urbach

Section 2

RESULTS AND CONCLUSIONS

Section 2
RESULTS AND CONCLUSIONS

Two key study objectives were established for this study: to establish the preliminary design for an Agena space tug and to identify the interfaces between the Agena vehicle and the space shuttle. Secondary objectives included preparation of test plans, cost estimates, performance data, and the conceptual design of an evolutionary Agena stage.

2.1 AGENA SPACE TUG DESIGN

A current and operational program Agena vehicle was selected as a baseline vehicle for the design effort. Very few changes were required to convert this baseline design into the Agena space tug configuration. The most extensive change was structural and involved adding two circumferential rings. These two rings include brackets for attaching the Agena and cantilevered payload to the support structure for mounting the Agena/payload in the cargo bay.

A multistart main propulsion system is needed for the low-earth-orbit mission, which requires multiple burn capability. The existing Gemini-Agena multistart engine design can be used to convert the baseline vehicle to a multistart configuration.

2.2 SPACE SHUTTLE/AGENA INTERFACE

The complete physical interface, between the combined Agena space tug/payload combination and the space shuttle cargo bay, consists of a support structure, three interconnections with the Agena space tug, and the Agena/payload service panel. A study groundrule requires that all interfaces between the Agena/payload and the space shuttle pass through the service panel.

The three interconnections follow:

a. Oxidizer Emergency Dump
b. Fuel Emergency Dump
c. Main Electrical Umbilical Disconnect (J-100)

Both payload and Agena power, data, and communications functions are routed to the service panel through the Agena J-100 disconnect. The payload functions are wired direct to the J-100 connector through an Agena/payload interface cable. Therefore, no payload interconnect is required.

The existing types of flyaway disconnects currently used at the launch bases for Agena flights are used for the three interconnects to the Agena vehicle. These disconnects are mated during the Agena/payload installation into the shuttle orbiter and remain connected until just before orbital deployment. The two propellant emergency dump disconnects are dry when connected, and remain dry. There is, therefore, no spillage problem during the predeployment disconnect sequence. If propellant dump occurs as a result of a mission abort, the disconnects and lines will be wet; however, the propellant disconnects will not be activated, since deployment will not occur.

The three umbilical disconnects are mounted on the support structure. Mating of the Agena/payload/support structure combination to the orbiter during prelaunch operations therefore requires only one precision operation – the alignment of the support structure with respect to the orbiter cargo bay structure. Connecting the two emergency dump lines, the J-100 electrical umbilical cable, and the cargo bay instrumentation and deployment control cable completes the mating of the Agena/payload combination to the orbiter.

The support structure is designed so that sections can be added and very heavy payloads can be supported at their center of gravity.

The Agena/payload service panel serves as a junction and distribution box for various electrical connections and for control of the Agena emergency dump sequence. The service panel also serves as a coupling point between the fixed, installed overboard dump lines in the space shuttle structure and the flexible lines connected to the Agena.

2.3 DEVELOPMENT TEST PLANS

Four complete and detailed test plans were completed during the study:

a. Development
b. Qualification
c. Systems Test
d. Launch Base Operations

The development requirements for the Agena space tug are primarily caused by mission-peculiar required changes to the vehicle, since relatively few changes are needed for shuttle compatibility.

All of the cargo bay support equipment is new or is a modification of existing equipment; therefore it requires development testing and qualification and verification of proper functioning under simulated operational usage and environmental conditions. To prove out the complete Agena space tug flight system, an orbital flight and actual deployment of an Agena space tug is suggested. This test flight would be made with a full complement of interface and space shuttle equipment and would be the final Agena space tug system operational readiness check.

Systems test would be performed both at the factory prior to shipment and at the launch base after the Agena space tug is mated with the payload and support structure. The Launch Base Operations Plan delineates all tests and procedures required for the Agena, support equipment, GSE, and interfaces with the space shuttle. This plan covers all phases of the launch base operation from arrival at the launch base through liftoff.

2.4 LAUNCH BASE OPERATIONS

Launch base facilities for conducting Agena space tug systems test, tanking and storage, and vehicle servicing exist today at Pad 13. This facility could be used with no changes except on the stand for the physical accommodation of the support structure and the addition of a safety console to handle and display the required safety instrumentation.

Emergency dump and Agena safing could be controlled from either the existing propulsion or the new safety console.

The Agena space tug can be completely tanked with propellants and gases prior to its installation into the space shuttle cargo bay. If necessary, the Agena can then be stored vertically, fully tanked, for up to 14 days before being mated to the shuttle.

After the Agena is mated to the shuttle and all interfaces checked out, only two additional operations are required prior to liftoff:

a. Flight-Readiness Check
b. Azimuth-Only Inertial Sensor Alignment (If Mission Accuracies Require This Step)

2.5 SAFETY

A preliminary hazards analysis was completed on the Agena space tug and its required operations. Three significant problems and potential approaches for overcoming them have been identified:

a. Propellant Leaks
b. Bulkhead Reversal
c. Handling Fully Tanked Agena

Launch base records indicate that there have been no launch base Agena propellant leaks since 1962. Established techniques and launch base procedures used in achieving this record are directly applicable to the Agena space tug.

Recognizing that, in spite of this record, propellant leaks could occur, a set of safety instrumentation for the Agena and cargo bay has been identified. These parameters are displayed on the Agena console at the shuttle mission specialist station and could also be displayed at the pilot's console. The same safety instrumentation would be used during the Agena tanking and storage operation. The possibility of bulkhead reversal can be controlled by maintaining the forward fuel tank pressure at a minimum of 5 psi higher than the aft oxidizer tank.

A fully tanked Agena space tug can be safely handled if established Agena handling and tanking procedures are stringently followed and certain safeguards are observed. An Agena stress analysis has shown that the Agena structure (unpressurized tanks) has sufficient margin to meet these handling requirements with the Agena fully tanked, with a cantilevered payload, and with the supporting structure.

The Agena would be tanked in the vertical position through use of existing launch base procedures. The safety instrumentation and emergency dump capability would be available. Lifting, tilting, and lowering the Agena/payload/support structure onto a transporter and into the shuttle cargo bay would require a dual crane setup with dual cables, hoists, and hooks. An additional static safety line would also be used.

2.6 EVOLUTIONARY STAGE DESIGN

The Agena space tug guidelines are also applicable to the evolutionary stage Agena. The same guidance, power, and communication subsystems previously defined for the Agena space tug are also used in the evolutionary stage design. Improvements defined by the Lockheed Agena improvement plan were reviewed and planned improvements in the engine and propellant tankage areas were selected that are nearly certain to be flight-proven to the first space shuttle flight. Performance and propellant tankage were optimized to the baseline synchronous equatorial mission since it is the performance design driver.

After the propellant tank configuration was established and a nominal propellant load of 48,800 pounds was selected, a point detail design was completed. The evolutionary stage is 120 inches in diameter and 275 inches long. All of the guidance, electronics, power, propellant tank pressurization, and communications system are common with those of the Agena space tug. Additional gaseous helium spheres were added to the propulsion pressurization system to accommodate the larger propellant tanks.

The impact of the evolutionary stage on the established space shuttle/Agena space tug interface is minimal. The cargo bay support structure requires redesign to accommodate the larger stage diameter. The weight tradeoff between the reduction in size of the support structure relative to the required increase in tube size and gage results in a nominal support structure weight increase of 30 pounds.

Since the same electronics are used in the evolutionary stage as in the Agena space tug, no changes are required in the Agena/payload service panel or the Agena console in the mission specialist station. Safety instrumentation, propellant tanking techniques, and vehicle deployment and flight operations all remain the same.

2.7 PERFORMANCE

Agena space tug performance was determined for an I_{sp} of both 290.8 and 310 seconds, since the latter figure results from incorporation into the Agena of approved and funded changes scheduled for completion prior to 1976.

Agena space tug performance for the three study baseline missions is given below:

Mission	Payload Weight (lb)	
	I_{sp} = 290.8 sec	I_{sp} = 310.0 sec
• Synchronous-Equatorial	2257	2804
• Interplanetary	3540	4225
• Low Earth, Sun-Synchronous Orbit*	9770 (each orbit)	10053 (each orbit)

Evolutionary stage performance was determined for two different propellant combinations:

a. High-Density Acid (HDA) and Unsymmetrical Di-Methyl Hydrazine (UDMH) at an I_{sp} of 310 sec

b. Nitrogen Tetroxide (N_2O_4) and Mono-Methyl Hydrazine (MMH) at an I_{sp} of 322 sec

Mission	Payload Weight (lb)	
	HDA/UDMH I_{sp} = 310.0 sec	N_2O_4/MMH I_{sp} = 322.0 sec
• Synchronous-Equatorial	13234	13956
• Interplanetary	16512	17276
• Low Earth, Sun-Synchronous Orbit*	9504 (each orbit)	9695 (each orbit)

*Agena space tug payload performance is constrained by space shuttle payload capability for polar orbit.

2.8 COSTS

A Level 6 and 7 WBS was used to derive a complete set of cost figures for both the Agena space tug and evolutionary stage. The costing guidelines and assumptions were the same for both vehicles. To cross-check the Agena space tug recurring and nonrecurring cost estimates, a special analysis was conducted to compare the historically derived costs of the Gemini Agena target vehicle with those of the Agena space tug.

The improved performance capability of the evolutionary stage can be obtained, on a recurring cost basis, for less than a 10 percent increase in price over the Agena space tug recurring cost. Similarly, the development costs for this stage are only about 15 percent more than the development costs for the Agena space tug.

AGENA SPACE TUG VS EVOLUTIONARY STAGE COSTS
($ Millions)

	Agena Space Tug	Evolutionary Stage	Cost Difference
Recurring			
Recurring Production Cost (Average Unit)	3.413	3.860	0.447
Recurring Operations Cost	0.646	0.710	0.064
Flight Operations and Services	0.135	0.135	0
Nonrecurring			
Vehicle System	38.598	45.792	7.194
Shuttle Orbiter Interface Equipment	1.871	1.871	0

2.9 CONCLUSIONS

The Agena space tug configuration is compatible with the space shuttle; it imposes minimum requirements and interface needs. Its high mass fraction results in a significant payload capability. Its operational flexibility results in simplified launch base operations using existing launch base procedures and available equipment. A number of safety problems have been identified and solutions have been established.

The Agena space tug design and operational simplicity result in low development and recurring costs.

The evolutionary stage is a growth version of the Agena space tug. Therefore, the space shuttle interface, simplified launch base operations, and existing facilities are equally applicable to the evolutionary stage. The larger-capacity propellant tanks and vehicle diameter result in slightly higher development and recurring costs; but a 500 percent gain in payload for the synchronous-equatorial mission is the payoff.

Section 3
RECOMMENDATIONS

Section 3
RECOMMENDATIONS

During the course of the study, several possible follow-on tasks were identified and are recommended for consideration. They are described here.

3.1 ATMOSPHERIC ABORT

The space shuttle may be required to abort a mission at any time between liftoff and Agena/payload deployment in orbit. Possible abort modes include flybacks, downrange landings, and once-around maneuvers. The implications of the presence of the Agena space tug as part of the payload in the cargo bay need to be identified and assessed and the resulting interface and vehicle design requirements identified.

3.2 MINIMUM INTERFACE

Since the Agena uses earth storable propellants, it is conceivable that it could be transported in the space shuttle cargo bay with no plumbing interface with the space shuttle. The primary areas of concern are the safety effects on shuttle operations of no provisions for Agena propellant vent or dump and the structural considerations for landing with a fully loaded Agena following a mission abort.

3.3 ON-ORBIT CHECKOUT AND DEPLOYMENT

Checkout of the Agena space tug and its deployment involves several different sequences and interfaces. These include deployment sequences and timelines, crew involvement, orbiter software effects, and Agena checkout timelines.

3.4 SUPPORT EQUIPMENT CONCEPTUAL DESIGN

Several items of equipment for operational support of the Agena space tug have been identified. This equipment would be installed either in the cargo bay or in the orbiter itself. The present study has established conceptual feasibility and has produced the preliminary design for the equipment to be located in the cargo bay. A firm study guideline limited Agena/shuttle interface definition beyond the Agena/payload service panel. Therefore, additional work is needed in such areas as emergency dump line routing, preliminary design of the Agena service console located in the mission specialist station, and the Agena/payload software interface with the orbiter.

3.5 AGENA SPACE TUG PAYLOAD SUPPORT

Of the more than 320 Agena flights, over 80 percent have been in a spacecraft configuration performing earth orbit missions of from 2 weeks to more than 1 year. In the spacecraft configuration the Agena has furnished continuous support to the payload. Such support typically included orbit insertion and maneuvers, guidance and attitude control, navigation, electrical power, data management, discrete commands, and communications.

For application to space shuttle operations the Agena could, in addition to the above listed functions, support the payload during flight readiness and predeployment checks. This task would identify items of equipment and functions that are common between the payload and the Agena for both orbital checkout and flight operations. The payload weight and cost savings would be determined for these Agena/payload combinations and the utilization by the payload of available Agena functional capability.

3.6 SAFETY ANALYSIS

A more detailed safety analysis is needed to identify all critical hazards and to establish feasible remedial or corrective measures. This analysis should include all ground operations through liftoff, ascent, and orbital deployment. Hazards incident to mission abort and the corresponding Agena safing requirements should also be included.

3.7 MOCKUP SUPPORT OF ORBITER DESIGN

As the orbiter design work moves into Phase C it will be necessary to establish certain cargo bay interface requirements more firmly. Among these are Agena/payload support structure attachment point locations and loads, the location of the Agena/payload service panel, routing of emergency dump lines, accessibility both on pad and on orbit, and vehicle installation and alignment problems.

The above data and resulting orbiter design requirements can be developed with the aid of structural mockups and cargo bay layouts.

3.8 TANDEM AGENA SPACE TUG

A preliminary investigation shows that a marked payload capability increase can be obtained by utilizing a "smart" and "dumb" Agena in a tandem arrangement. Two tandem Agena space tugs and a payload can be mated and carried in the cargo bay and inserted into a 28.50 deg inclination, circular, 100 nm altitude orbit. Only one shuttle flight is required.

The evolutionary stage also shows the same potential for payload performance gain by a tandem stage arrangement. Candidate configurations should be established and evaluated in terms of performance and cost.

3.9 IMPROVED AGENA SPACE TUG

A firm guideline for the existing study was to utilize existing hardware and technology, with no allowance for improvements on technology development. The introduction of 1976-1980 technology advances and higher energy storable propellants will produce even higher agena space tug and evolutionary stage payload performance. The tradeoff between these performance advances and the resulting cost increases should be evaluated and promising concepts introduced into the Agena space tug and evolutionary stage designs. Space shuttle interface effects would then be determined and final recommended concepts established.

Section 4

OPERATIONAL CHARACTERISTICS, INTERFACES, AND DESIGN CHARACTERISTICS

Section 4

OPERATIONAL CHARACTERISTICS, INTERFACES, AND DESIGN REQUIREMENTS

Preliminary operational requirements have been established for the application of an Ascent Agena as an expendable tug for use with a reusable space shuttle as defined by the MSC Space Shuttle User's Guide* and the NAR Phase B final report.** Physical, functional, and procedural interface requirements are identified; these requirements are based on the proposed shuttle configuration, characteristics, operational plans, and unmanned missions representative of those that might be selected from the NASA mission model for an expendable tug.

The Agena prelaunch operational sequences with the shuttle will be markedly different from those for expendable booster launch vehicles. The Agena will be much less involved in shuttle on-pad activities, particularly the terminal countdown. Agena/payload installation and checkout would typically occur approximately 96 hr before launch, with the shuttle orbiter in the horizontal attitude at the Maintenance and Checkout Facility (MCF). Except for limited safety monitoring via the shuttle data bus, the Agena and payload will be powered down during shuttle erection, mating, and transfer to the launch pad. The Agena propellants and gases will probably be loaded 1 to 2 weeks before launch, before the Agena is installed in the orbiter cargo bay. An alternate plan for pad loading 6 to 8 hr before launch is also considered. In either event, a final status verification prior to launch will be required.

During ascent, the Agena and its payload will remain in the powered-down inactive state except for the Agena guidance system and safety monitors. An on-orbit status check will be performed after shuttle injection and prior to Agena/payload deployment.

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*Space Shuttle User's Guide, Edition 1, NASA-MSC, 21 June 1971
**Space Shuttle Phase B Final Report, Vol II, NAR, 26 March 1971

Following deployment on orbit, the Agena will be capable of independent operation under ground command, although the orbiter capability for primary control or data relay may also be selected.

4.1 MISSION DESIGN REQUIREMENTS

To demonstrate the versatility and performance capability of the Agena tug vehicle in combination with the space shuttle, three reference missions based on the mission modes suggested in the NASA MSC Statement of Work were defined: (1) a geosynchronous mission, (2) a planetary mission (Viking type), and (3) a low-earth-orbit mission requiring a plane and altitude change followed by return to the shuttle orbit after 30 days.

4.1.1 Geosynchronous Mission (Mission I)

This is a synchronous-equatorial mission based on a space shuttle/space tug mission in which synchronous orbit injection over the mid-Pacific is desired. In generating a transfer sequence from a 100-nm circular orbit at 28.3-deg inclination angle to 19,330-nm circular equatorial orbit, an elliptical drift orbit (100-nm perigee, 17,000-nm apogee) of approximately 9 hr period was employed. The purpose of this intermediate orbit is to position the arrival at synchronous altitude to coincide with the proposed mid-Pacific operational area. If it is assumed that the first burn of the Agena at the second descending node of the 100-nm circular orbit sets up the intermediate drift orbit and that after one revolution a second burn raises apogee to synchronous altitude, the first arrival at that apogee and the associated injection into synchronous-equatorial orbit results in a mid-Pacific Ocean station location. The Agena maneuvers reflect Hohmann transfer requirements and an optimum (with respect to minimum ΔV) perigee/apogee split of the inclination angle change. A flight performance reserve of 1 percent of the total mission ΔV is used in the velocity profile for the purpose of evaluating payload capability. The mission description, identification of propulsion events, the sequence of those events, velocity requirements, and the specification of either main engine or attitude control system applicability for the synchronous-equatorial reference mission are summarized in Table 4-1. Figure 4-1 is a representation of the orbit maneuvers for the geosynchronous mission.

Table 4-1

SYNCHRONOUS-EQUATORIAL MISSION CHARACTERISTICS

SYNCHRONOUS EQUATORIAL MISSION
INITIAL CONDITIONS 100NM CIRC, 28.3 DEG INC EARTH ORBIT
TARGET CONDITIONS 19330NM CIRC, 0 DEG INC EARTH ORBIT
FINAL CONDITIONS

COMMENTS
OUTBOUND FLIGHT PROFILE HOHMANN XFER OPT INCL SPLIT
RETURN FLIGHT PROFILE
STAY TIME AT TARGET

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE
INITIAL	SPACE TUG DEPLOY (INCL=28.3)	0: 0: .0		
		0: 0: .0	0.	RCS
	PHASING ORBIT INJ (INCL=26.1)	0: 0:30.0		
		0: 0:32.9	7932.	MAIN
	XFER ORBIT INJ (INCL=26.1)	0: 9:40.9		
		0: 9:41.0	260.	MAIN
	MIDCOURSE + ATTITUDE CONTROL	0:10:23.0		
		0:10:23.5	12.	RCS
	SYN EQ INJ (INCL=0.0)	0:14:52.5		
		0:14:53.5	5865.	MAIN
	FLIGHT PERF RESERVES	0:14:53.5		
TARGET 1		0:14:53.5	140.	MAIN

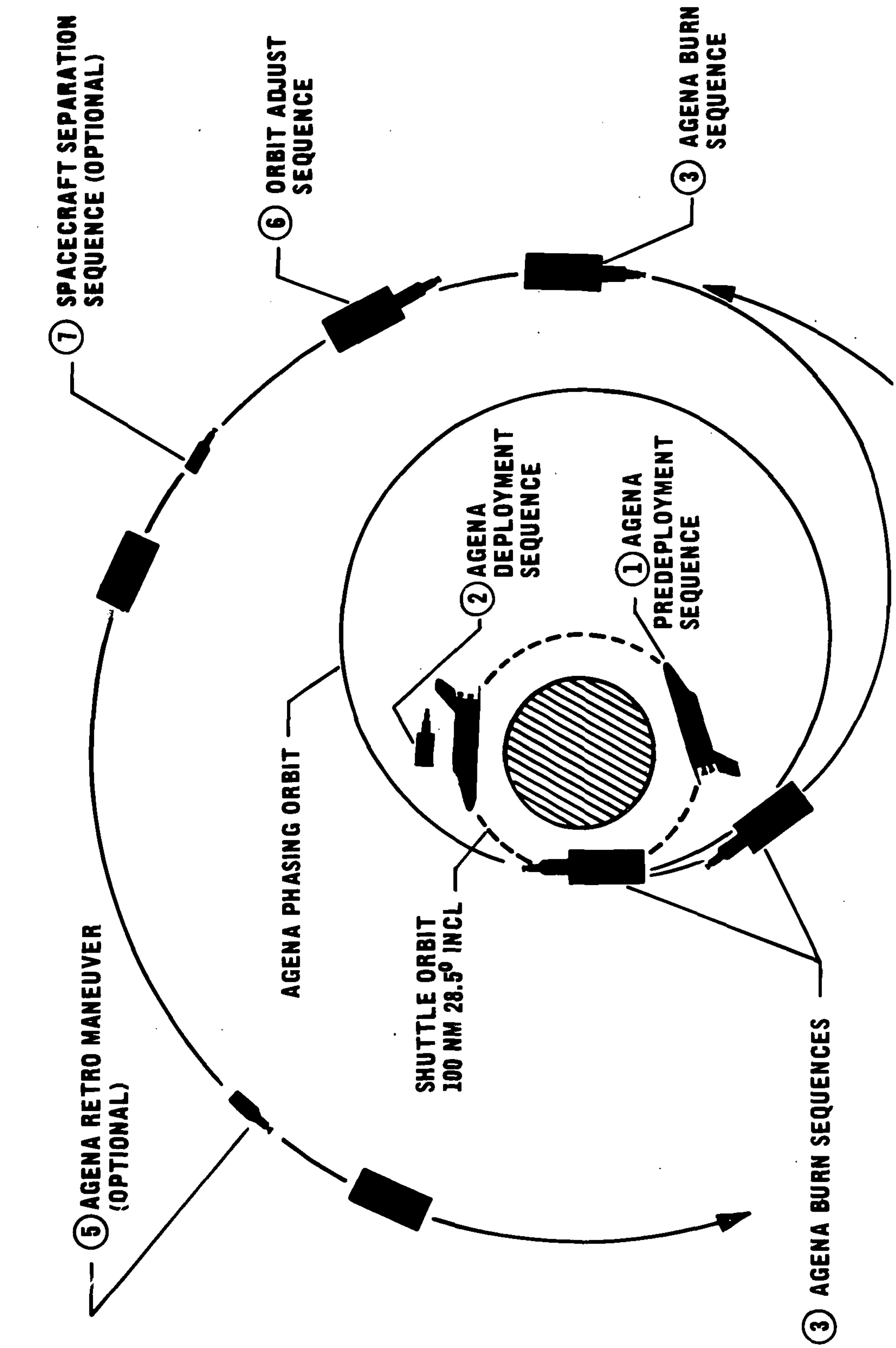


Fig. 4-1 Geosynchronous Mission Profile

4.1.2 Interplanetary Mission (Mission II)

The interplanetary mission selected for the study was based on requirements stemming from the current Viking Program. Examination of various Viking flight profiles gave rise to such design parameters as (1) a Mars orbit of h_p = 1500 km and a period of 24.6 hr and (2) approximately 4200-fps retro-velocity requirement to enter the Martian orbit. If it is assumed that the space shuttle and Agena tug are operational in 1979, examination of the early opportunities occurring thereafter (on approximately a 26-month cycle) in terms of the requirements specified above led to selection of a representative launch date of 12 Nov 1981, the beginning of an approximate 10-day launch window. This date allows the parking orbit (100-nm circular and 28.3-deg inclination) to be initially oriented for an in-plane departure at the beginning of the window. The corresponding velocity requirement for trans-Mars injection is 12,250 fps. If the orbit departure maneuver is delayed, the parking orbit precession will cause the desirable departure asymptotes to fall outside the parking orbit plane, resulting in a ΔV requirement of approximately 13,000 fps after 10 days. It is assumed that for the 10-day delay the three-impulse technique is used to minimize the penalty for the out-of-plane condition. For the nominal launch conditions and under the assumed ground rules, the launch date of 12 Nov 1981 would result in a Mars orbit insertion maneuver on 17 Sep 1982. A flight performance reserve of 1 percent of the total ΔV was again used to calculate performance capability. The mission description, identification of Agena propulsion events, the sequence of those events, velocity requirements, and the specification of either main engine or attitude control system applicability for the interplanetary reference mission are summarized in Table 4-2. Figure 4-2 is a representation of the orbit maneuvers for the 1981 Viking mission.

4.1.3 Low-Earth-Orbit Mission (Mission III)

The design characteristics required of the reference mission in this category were the attainment of a low earth orbit, multiple burns (greater than three), and a relatively long mission duration. Again, as in the case of the other missions, the actual design parameters were based upon proposed programs. A recently completed analysis providing the minimum ΔV profile for the delivery of two identical payloads to two different low circular orbits, both sun synchronous, had the necessary characteristics to be

Table 4-2

INTERPLANETARY MISSION CHARACTERISTICS

```
1982 VIKING MISSION
   INITIAL CONDITIONS  100NM CIRC, 28.3 DEG INC EARTH ORBIT
   TARGET  CONDITIONS  TRANS MARS INJECTION
   FINAL   CONDITIONS

   COMMENTS
      OUTBOUND FLIGHT PROFILE   10 DAY LAUNCH PERIOD
      RETURN FLIGHT PROFILE
      STAY TIME AT TARGET
```

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE
INITIAL	TUG DEPLOY, FROM SPACE SHUTTLE	0: 0: .0		
			4.	RCS
		0: 0: .4		
	TRANS-MARS INJECTION	0: 0:30.4		
			12250.	MAIN
		0: 0:34.5		
	FLIGHT PERFORMANCE RESERVE	0: 0:34.5		
TARGET 1			120.	MAIN
		0: 0:34.5		

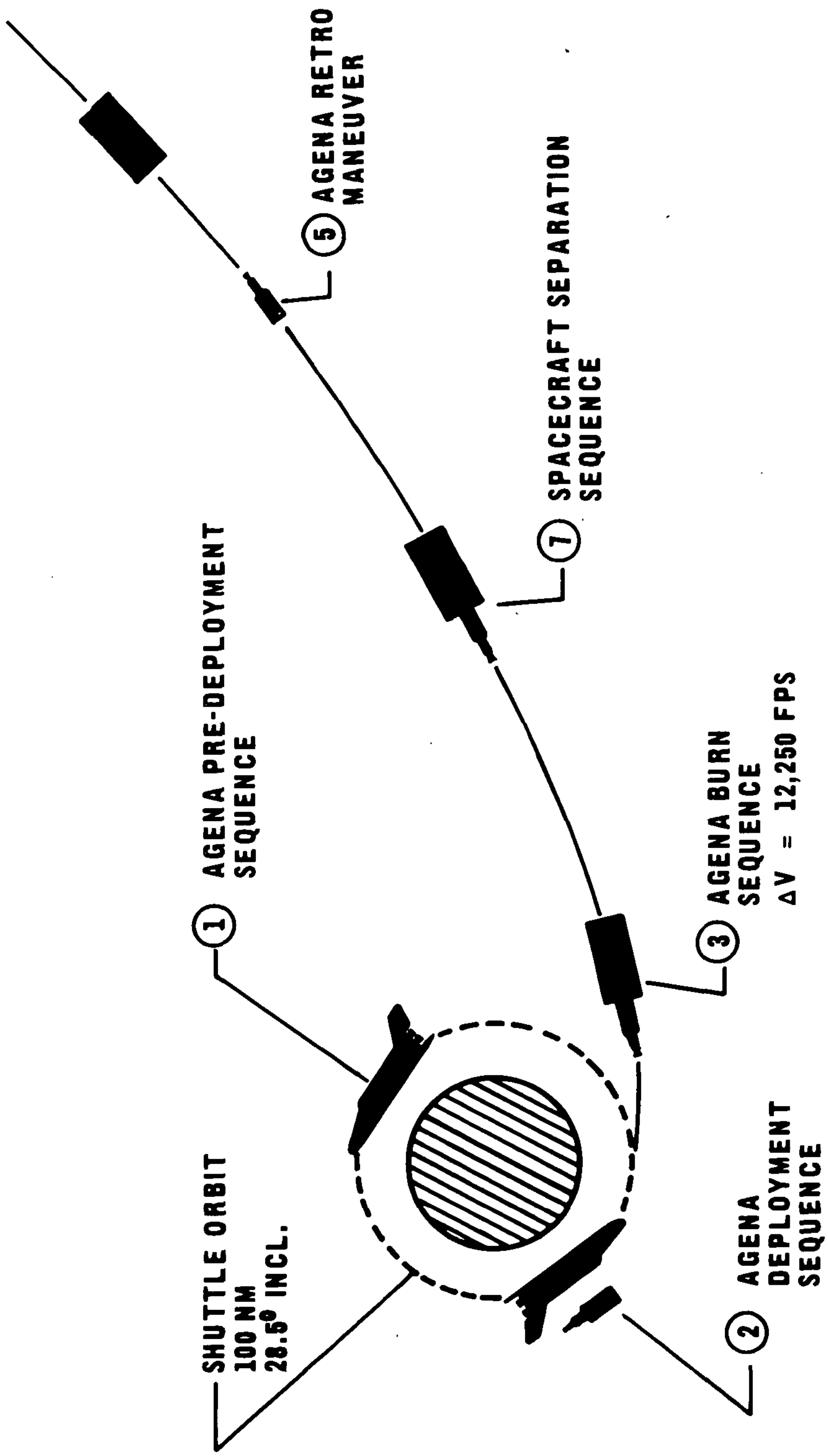


Fig. 4-2 Interplanetary Mission Profile

used as the reference case in the low-earth-orbit category. The initial orbit is 600 nm circular at 99.884 deg inclination. At this point, half the payload weight capability is deployed; after 1.3 revolutions at 600 nm, a transfer is initiated to achieve a 400-nm circular orbit at 98.262 deg. After approximately 29 days at 400 nm, during which the Agena remains attached to the second payload, a final transfer is accomplished to attain a 100-nm circular orbit at 98.262 deg inclination (no plane change), bringing the second payload back for space shuttle retrieval. All maneuvers (six main-engine burns) are based upon Hohmann transfers and optimum perigee/apogee splits of the required inclination angle changes. Because the total mission ΔV is relatively small, the maximum payload capability of the Agena for this mission yields an ignition weight greater than the space shuttle capability if an in-plane shuttle launch for the initial orbit (an inclination of 99.884 deg) is assumed. A trade study will therefore be required to examine the effects of shuttle orbit inclination and Agena propellant offloading for the purpose of determining the optimum parameters that will maximize injected spacecraft weight. The flight performance reserve requirements shown in the velocity profile and used to calculate payload capability are based upon 1 percent of the ΔV from initial conditions to the first target (600 nm), from the first to the second target (400 nm), and from the second target back down to 100 nm. The mission description, identification of Agena propulsion events, the sequence of those events, velocity requirements, and the specification of either main engine or attitude control system applicability for the low-earth-orbit reference mission are summarized in Table 4-3. Figure 4-3 is a representation of the orbit maneuvers for the mission as described above.

Table 4-3

LOW-EARTH-ORBIT MISSION CHARACTERISTICS

SUN SYNCHRONOUS MISSION
INITIAL CONDITIONS 100NM CIRC, 92.1 DEG INC EARTH ORBIT
TARGET CONDITIONS TARGET 1- 400NM CIR, 99.584 DEG INC TARGET 2- 400NM CIR, 98.262 DEG INC
FINAL CONDITIONS 100 NM CIRC 98.262 DEG INCL

COMMENTS
OUTBOUND FLIGHT PROFILE HOHMANN XSFER OPT INC SPLIT
RETURN FLIGHT PROFILE HOHMANN TRANSFER
STAY TIME AT TARGET 4.3 REV --- 29DAYS

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE
INITIAL	SPACE TUG DEPLOY (INCL=92.1)	0: 0: .0		
		0: 0: .0	0.	RCS
	XSFER ORBIT INJ (INCL=94.9)	0: 0:30.0		
		0: 0:31.5	1510.	MAIN
	MIDCOURSE + ATTITUDE CONTROL	0: 0:56.3		
		0: 0:57.5	7.	RCS
	INJ 400NM CIR ORB (INC=99.584)	0: 1:21.5		
		0: 1:23.3	2195.	MAIN
	FLIGHT PERFORMANCE RESERVE	0: 1:23.3		
TARGET 1		0: 1:23.3	45.	MAIN
	XSFER ORBIT INJ (INCL = 99.04)	0: 3:40.8		
		0: 3:41.0	465.	MAIN
	MIDCOURSE + ATTITUDE CONTROL	0: 4: 7.7		
		0: 4: 8.1	5.	RCS
	INJ 400NM CIR ORB (INC=98.262)	0: 4:33.1		
		0: 4:33.3	456.	MAIN
	FLIGHT PERFORMANCE RESERVE	0: 4:33.3		
TARGET 2		0: 4:33.3	9.	MAIN
	XSFER ORBIT INJ (INCL= 98.262)	29: 4:33.3		
		29: 4:33.5	504.	MAIN
	MIDCOURSE + ATTITUDE CONTROL	29: 4:57.4		
		29: 4:59.1	27.	RCS
	INJ 100NM CIR ORB (INC=98.262)	29: 5:22.1		
		29: 5:22.3	514.	MAIN
	FLIGHT PERFORMANCE RESERVE	29: 5:22.3		
FINAL		29: 5:22.3	10.	MAIN

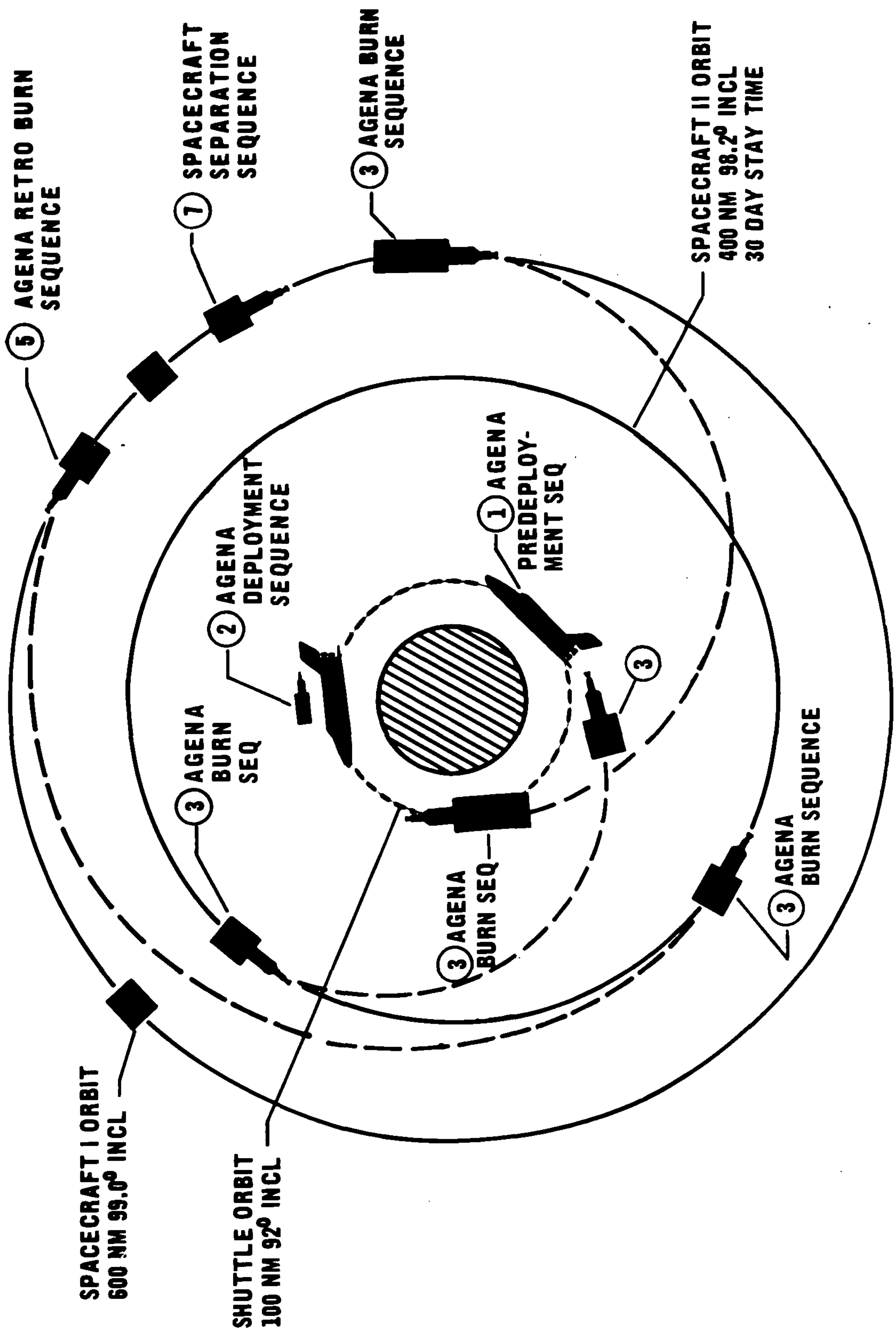


Fig. 4-3 Low-Earth-Orbit Mission Profile

4.2 SYSTEM DESIGN REQUIREMENTS

The design and operational requirements of an expendable Agena tug carried to orbit within the shuttle orbiter cargo bay will differ from those of an expendable Agena upper stage on a conventional launch vehicle. Those requirements that differ from the current Ascent Agena requirements are presented in this section; they reflect two basic ground rules:

1. The Agena tug must have minimum impact on the shuttle configuration and operation and must not require a dedicated orbiter for Agena operations.
2. The baseline Agena tug must be based on the Ascent Agena, with minimum modification to satisfy the requirements for use with the shuttle.

4.2.1 Agena Tug System Definition

The Agena vehicle will be configured for use as an upper stage on the Space Transportation System. Its function is to transport and deliver payloads from the shuttle orbit to the desired spacecraft orbit and position.

For the purpose of this study, the payloads are considered to be separable spacecraft that operate independently of the Agena; however, provisions for integrated, non-separable payloads should also be considered with respect to certain subsystems, such as power supply and telemetry.

The Agena and the spacecraft will be carried to the shuttle orbit within the shuttle cargo bay and will be considered only as cargo during the ascent flight. The Agena and the spacecraft will be deployed at the nominal shuttle orbit of 100-nm altitude at either the inclination corresponding to the spacecraft orbit or that inclination which will permit the most economical spacecraft injection.

For the purpose of this study, the Agena is used as an expendable stage only, with no reuse capability or value.

For nominal conditions following deployment by the orbiter, any required monitoring of telemetry data or command and control of the Agena vehicle will be performed by available ground stations. As a design goal, the orbiter should have the option of controlling and monitoring the Agena.

The maximum Agena/payload weight, including Agena support equipment, is 65,000 lb, corresponding to the structural design load of the orbiter. The maximum nominal cargo weight for landing is 40,000 lb; however, since the Agena/payload will be involved in landing only in the event of a mission abort condition, a higher landing weight may be acceptable. (Note that since the total propellant load of the Agena is 13,837 lb, the 40,000 lb landing weight cannot be satisfied by propellant dump if the combined Agena/payload weight exceeds 53,837 lb.) The variation of the shuttle cargo capability with orbit inclination is shown in Figure 4-4; the three design missions used for this analysis are also indicated.

The shuttle ascent trajectory will include a 50 x 100 nm transfer orbit with circularization at the 100-nm apogee. Flight time from launch to circular orbit injection is approximately 45 min.

After injection into shuttle orbit, the Agena may remain within the shuttle cargo bay for a period of up to 3 hr. Nominally, it is assumed that the Agena/payload checkout and deployment will take place during the first orbital pass.

Mission abort provisions for the Agena will be limited to propellant dump capability. Propellant will be dumped to receiver tanks prior to shuttle liftoff and overboard after liftoff. Thrust for propellant orientation for zero-g dumping on orbit will be provided by the orbiter. Abort operations during ascent flight will not be considered for this analysis.

4.2.2 Mechanical Interface Definition

The Agena/payload configuration will be carried to the shuttle orbit (100-nm altitude) as cargo within the orbiter cargo bay.

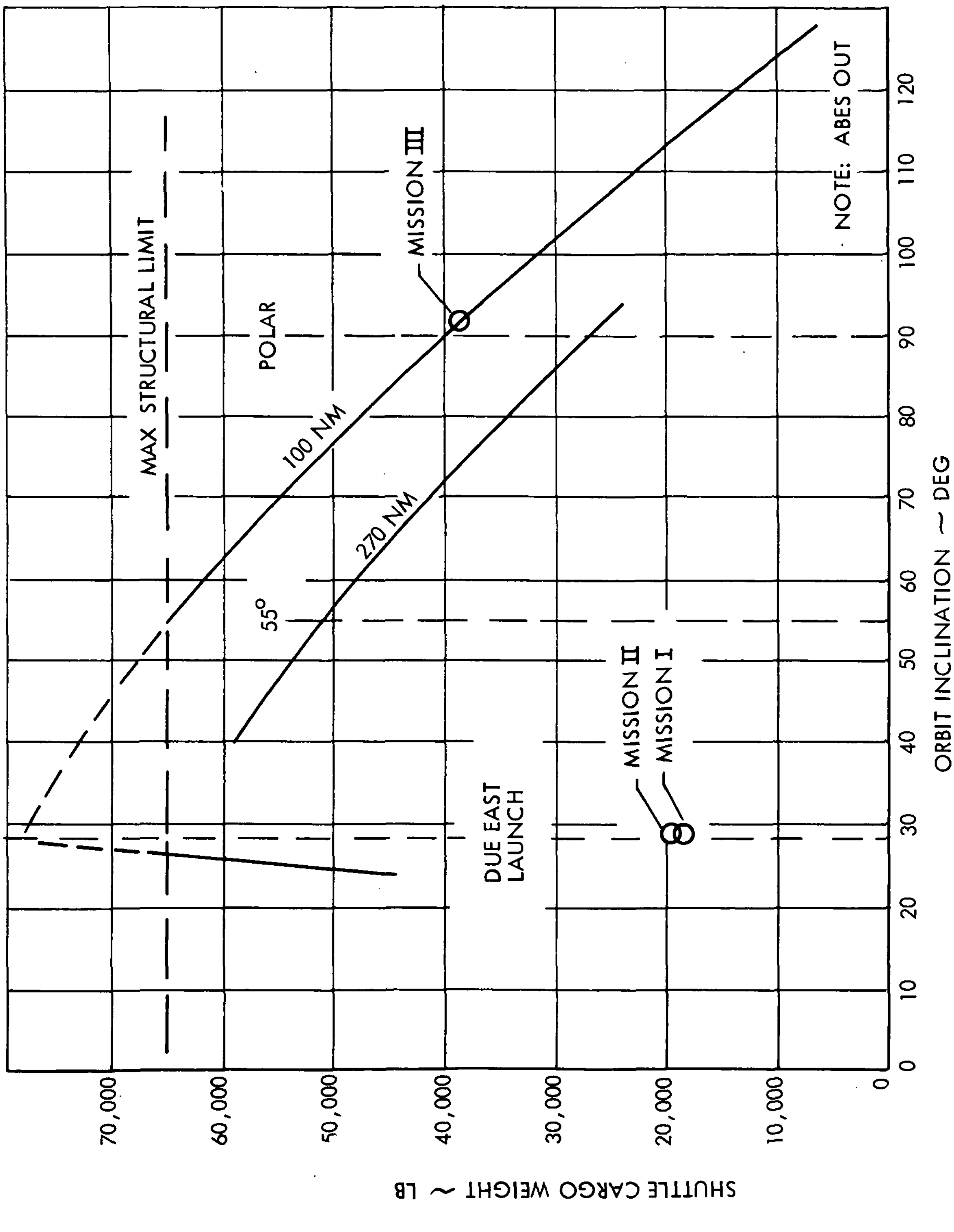


Fig. 4-4 Shuttle Cargo Capability

4.2.2.1 Cargo Bay Envelope. The orbiter cargo bay (Fig. 4-5) will accommodate a payload or combinations of payloads equal to or less than 60 ft in length and 15 ft in diameter. There are no minimum payload length or diameter constraints. The orbiter also provides the clearance envelope in the cargo bay to avoid interference between the orbiter and the payload.

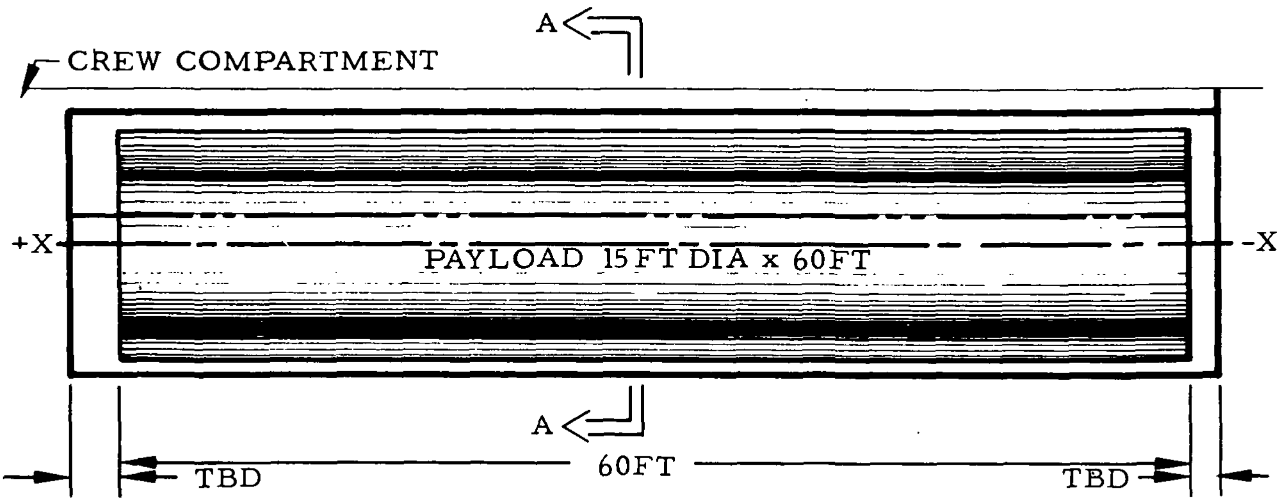
4.2.2.2 Cargo Bay Doors. The orbiter will have the capability of exposing the entire length and the full width of the cargo bay. With the cargo bay door open, an unobstructed 180-deg lateral field-of-view is available to the payload at the plane of the hinge line, as shown in Fig. 4-6.

4.2.2.3 Cargo Bay Structural Hard Points. The Agena structural attachment must be designed to be compatible with the structural hard points provided in the cargo bay. These points are located outside the 15-ft-diameter cargo mold line and will transmit cargo loads to the orbiter primary structure. They will interface with the cargo or cargo adapters and are capable of supporting the cargo under all mission phases. In the design of the Agena structure to mount to these points, therefore, a three-point suspension system must be considered to simplify the structural interactions of the cargo and the orbiter.

These hard points are spaced 20 in. apart along the cargo bay length. Their location is indicated in Fig. 4-7.

4.2.2.4 Mass Properties. The orbiter is capable of supporting cargo weights of from zero to 65,000 lb. Maximum allowable weight for landing is 40,000 lb. The Agena/payload configuration must be located so that the combined center-of-gravity location is within the limits indicated in Figs. 4-8 and 4-9.

The longitudinal center-of-gravity restriction is especially important for entry and landing phases of the mission. Since this will represent only an abort case for the Agena flights, the resulting c.g. location with the Agena propellant dumped must be investigated.



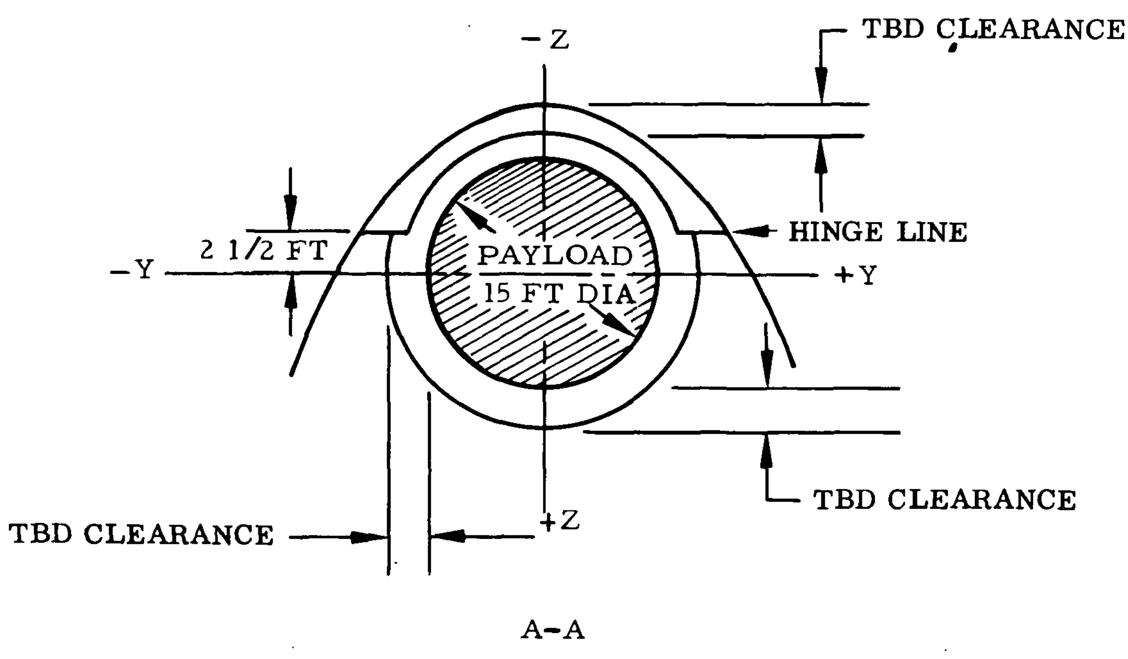


Fig. 4-5 Orbiter Payload Bay

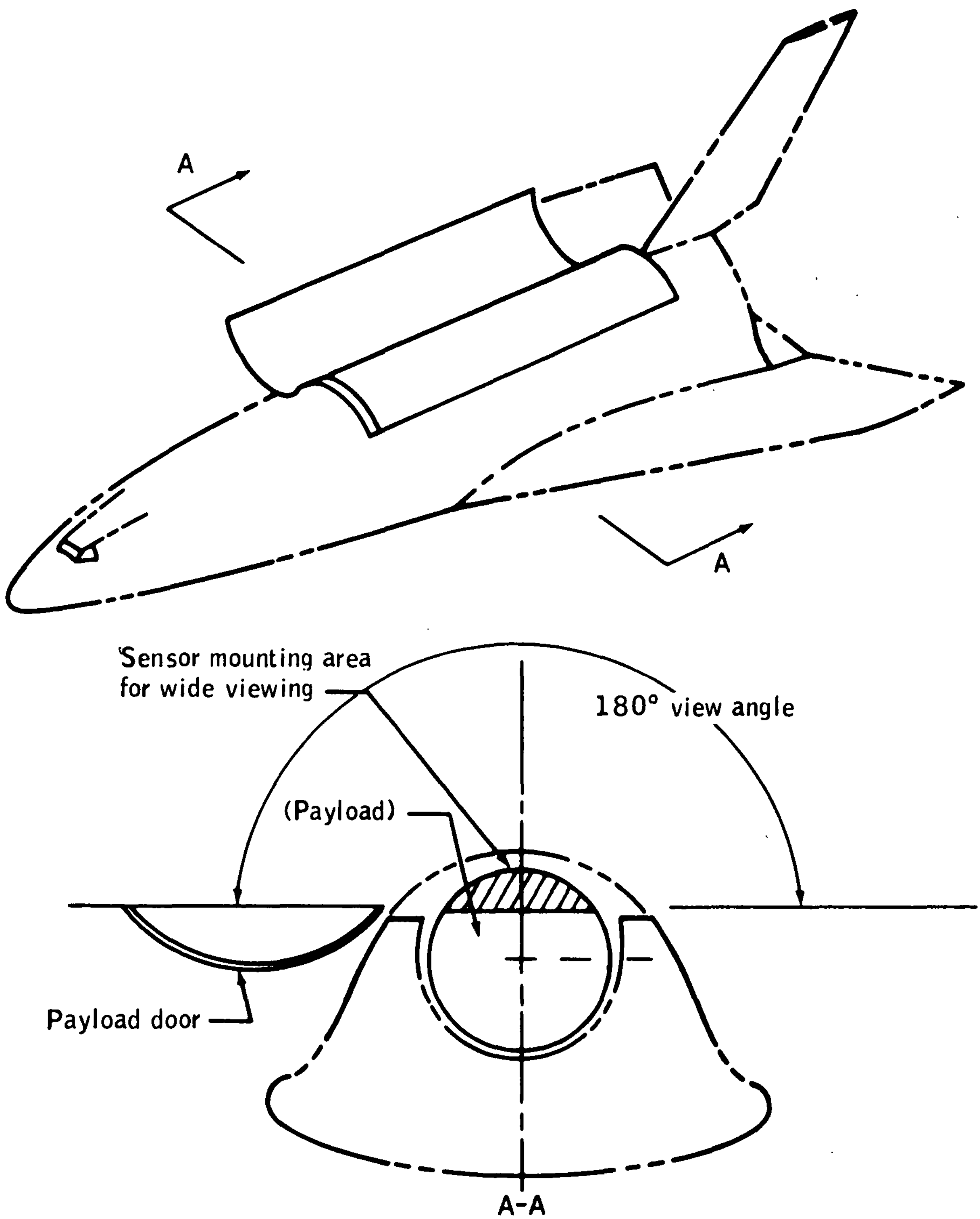


Fig. 4-6 Fixed Payload Field-of-View

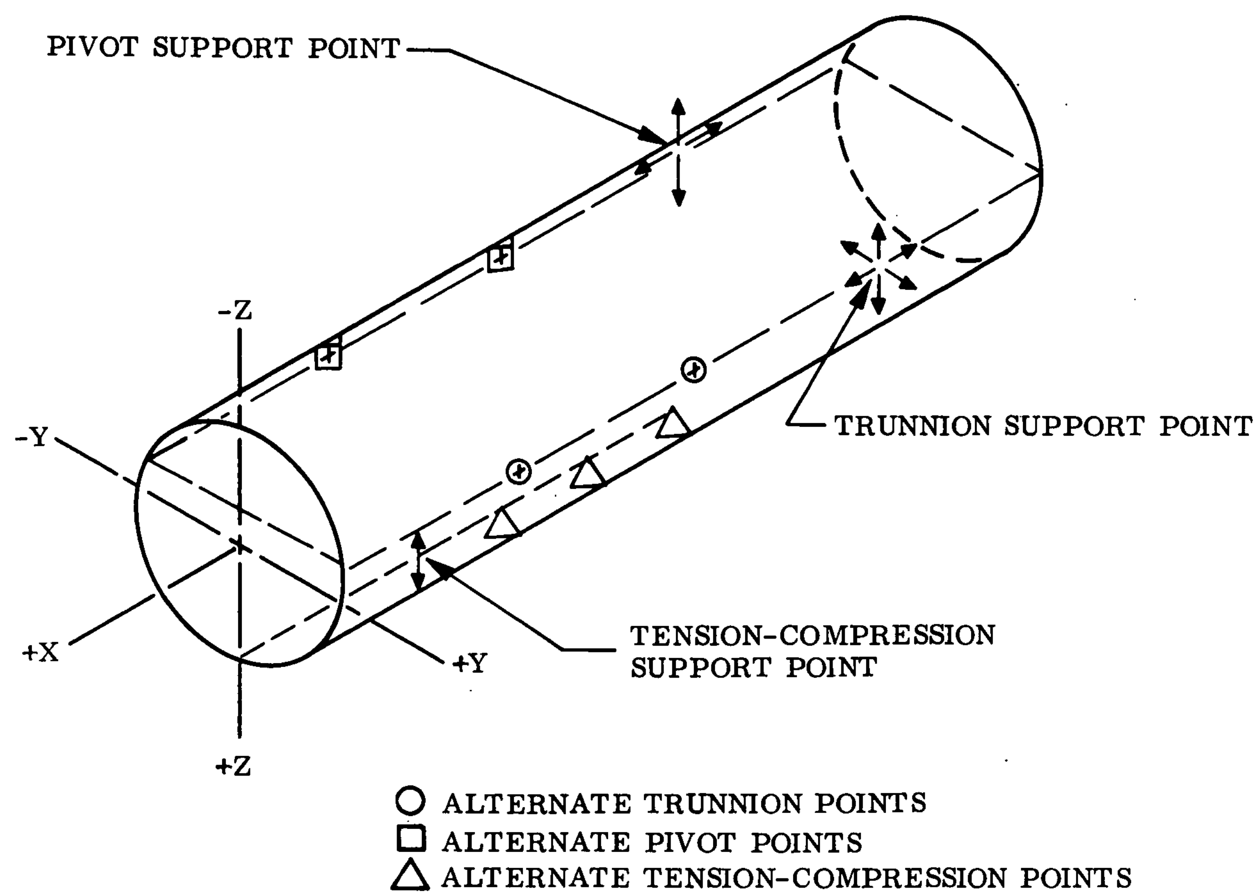


Fig. 4-7 Orbiter Payload Mechanical Attachment

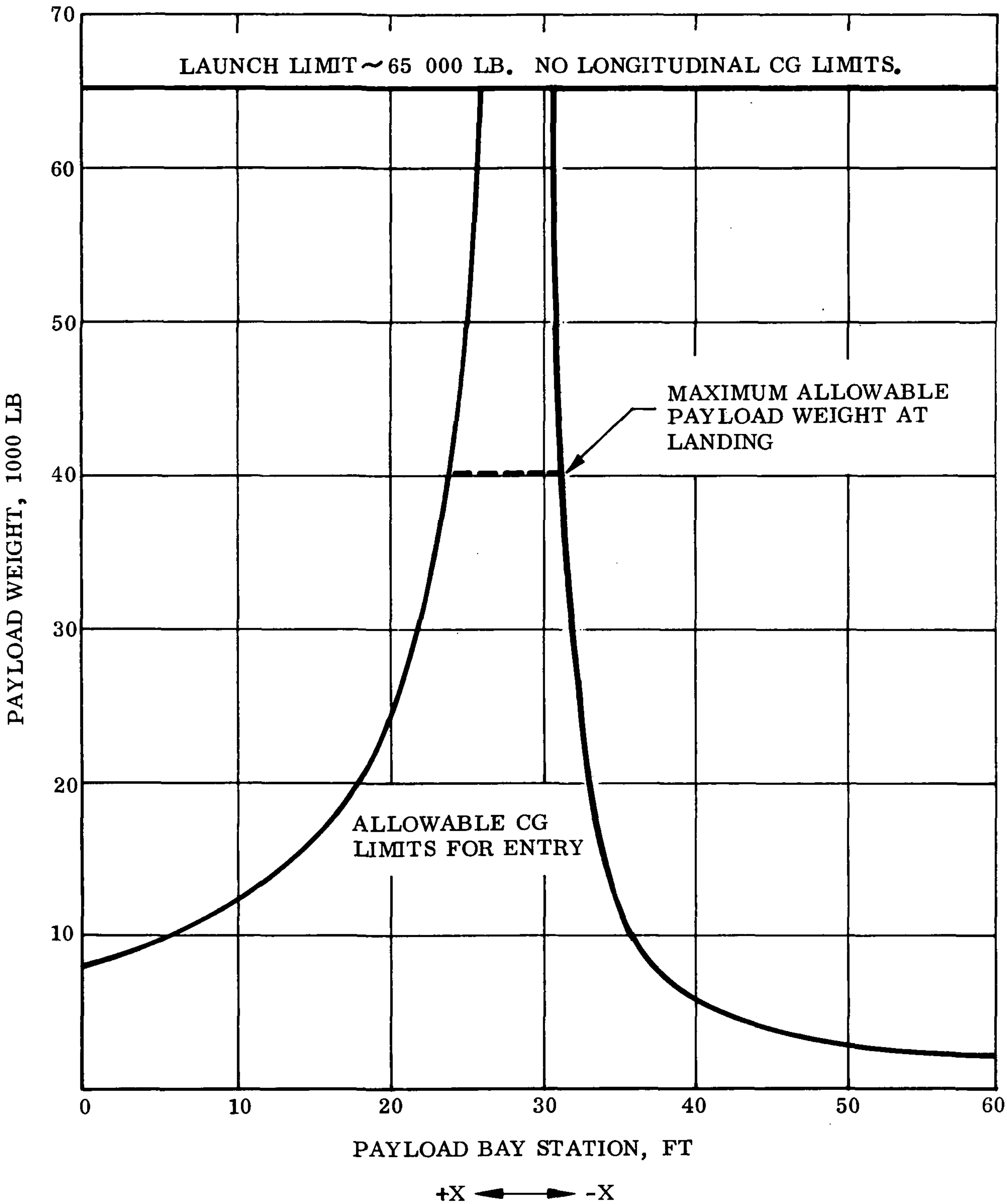


Fig. 4-8 Payload Longitudinal Center-of-Gravity Limits

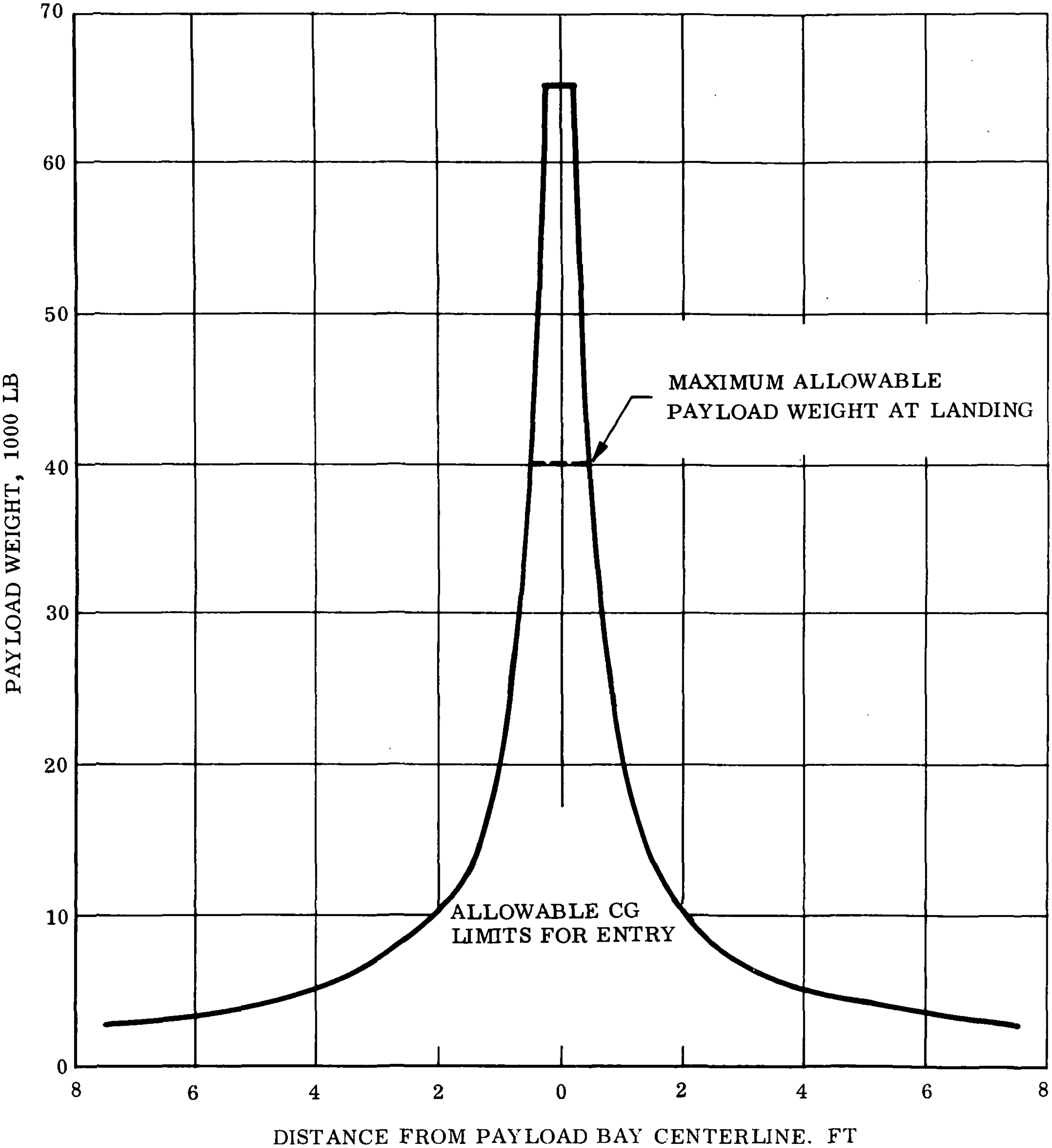


Fig. 4-9 Payload Lateral and Vertical Center-of-Gravity Limits

4.2.2.5 Access to Cargo on Launch Pad. The orbiter and launch facility allow access to the cargo for cargo installation, service, and removal in the orbiter flight preparation area and on the launch pad. Access is normally through the open cargo bay doors. Personnel and limited cargo access to the cargo bay is also available through the hatch between the orbiter crew compartment and the cargo bay.

4.2.2.6 Cargo Replacement. The Agena installation in the orbiter must be designed so that the spacecraft or the complete Agena/payload/adapter unit can be removed and replaced in not more than 10 hr elapsed time.

4.2.2.7 Access to Cargo on Orbit. On-orbit access to the Agena/spacecraft configuration in the unpressurized cargo bay must be provided. This access may be through a retractable tunnel.

4.2.2.8 Agena/Payload Attachment System. Where practical, a family of standardized cargo adapter structures of various configurations and capabilities will be used to mount cargo in the orbiter.

The Agena adapter must be designed so that the Agena/payload configuration can be assembled with the adapter and the entire unit loaded into the orbiter. This adapter must be compatible with the structural hard points in the payload bay and also with the deployment mechanism.

4.2.2.9 Adapter Weight. The weight of the Agena/payload adapter structure is considered part of the cargo and is therefore chargeable to the Agena system.

4.2.2.10 Release of Agena/Payload From Adapter. The Agena/payload adapter must be designed so that the Agena/payload configuration can easily be released from the adapter with a minimum of disturbance to both the orbiter and the Agena/payload configuration.

4.2.2.11 Design Loads. The Agena/payload attachment system must be designed to support the Agena/payload configuration for the load factors defined in par. 4.2.7, Environmental Constraints.

4.2.2.12 Cargo Deployment and Retrieval Mechanism. The orbiter will provide a standard cargo deployment and retrieval mechanism (Fig. 4-10). This mechanism is capable of deploying the cargo clear of the orbiter mold line and will not intrude into the 60 by 15 ft cargo volume.

4.2.2.13 Design Responsibility. The design of the orbiter standard deployment and retrieval mechanism is not an Agena responsibility, and the weight of the standard deployment mechanism is chargeable to the orbiter weight. If the option of an Agena/payload deployment mechanism is selected, the additional weight will be charged against the Agena/payload.

4.2.2.14 Cargo Handling Station. The cargo deployment mechanism will be operated from the cargo handling station. This station, located just forward of the cargo bay as shown in Fig. 4-11, provides the flight crew with the controls, visibility, and displays required to deploy or retrieve the cargo. It is capable of being manned by one flight crewman in a shirtsleeve environment and provides visual access to the cargo supports and the attachment points for the deployment mechanism.

4.2.2.15 Agena Attachment Points. If the standard deployment mechanism is used for handling the Agena/payload configuration, attachment points must be provided on the Agena at a location that can be observed from the handling station. These attachment points must be designed to withstand loads in all three directions.

4.2.2.16 Loading Agena/Payload Into Orbiter. The Agena/payload and the attachment structure will normally be loaded into the orbiter as one unit while the orbiter is in a horizontal position. However, for cargo replacement on the pad, the system must also be capable of being removed and replaced with the shuttle in a vertical position. Such replacement must be completed at least 2 hr before launch.

4.2.3 Electrical Power

4.2.3.1 Agena Power Supply. The Agena electrical power supply system must be designed to meet the Agena power demand from deployment from the orbiter until the

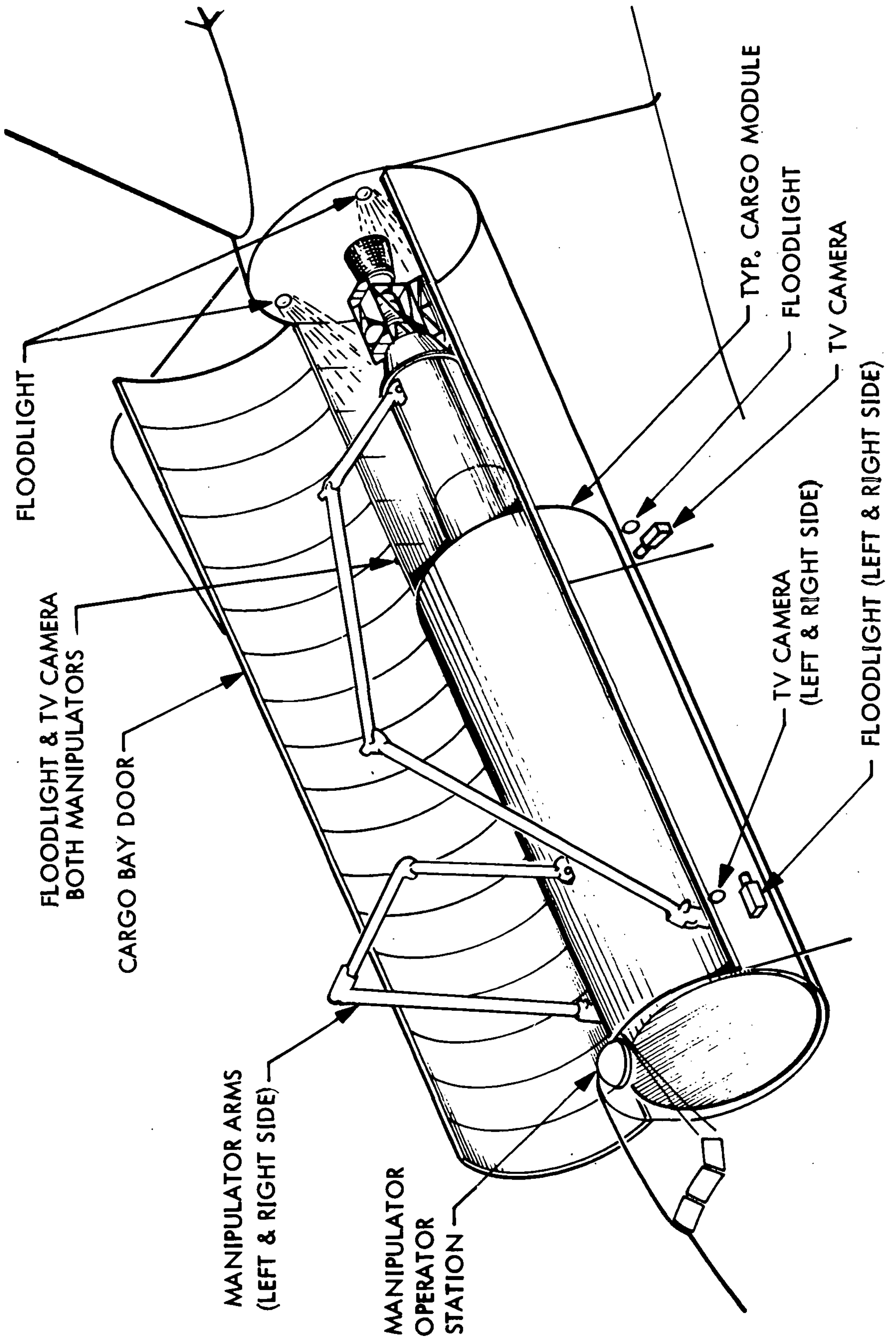


Fig. 4-10 Cargo Handling and Docking System

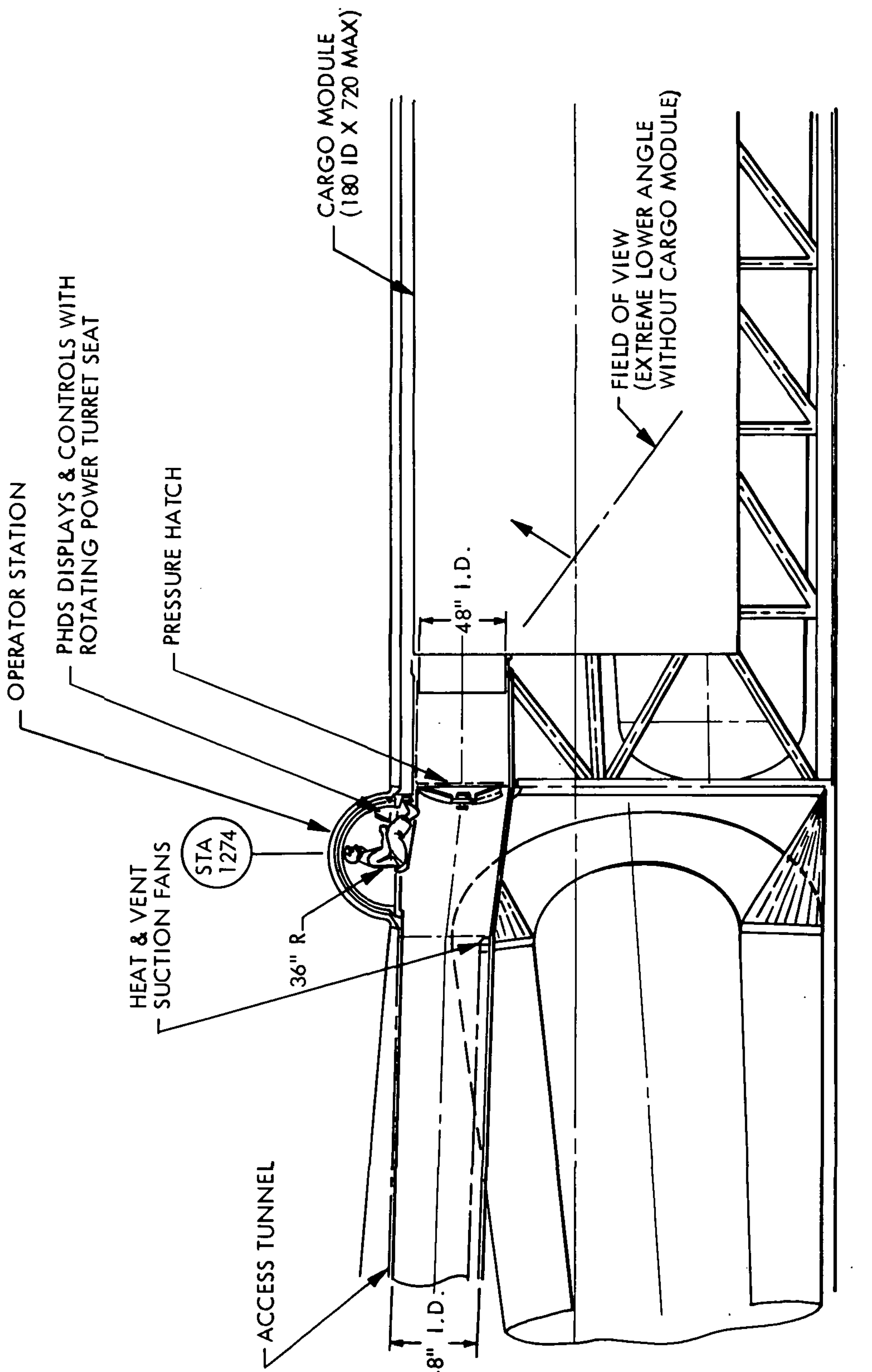


Fig. 4-11 Cargo Handling Station

mission is completed. It must be configured so that additional batteries can be added to the system to comply with the various mission power requirements and duration. Power profiles compatible with the mission duration and the equipment to be used must be determined. Normal contingency factors and margins are applicable.

4.2.3.2 Payload Power. The Agena payload is, for the purpose of this analysis, considered self-supporting with respect to electrical power.

4.2.3.3 Orbiter-Supplied Power. During ground checkout, countdown, and ascent flight to shuttle orbit, the Agena and the payload will receive electric power from the orbiter power supply system. The orbiter power will be supplied to the cargo with the following characteristics:

- Electrical Energy Allowance. 50 kw-hr
- Voltage. Regulated 34 VDC nominal,
  30 to 40 VDC range
- Transient Voltage Level. (TBD)
- Load. During periods of peak orbiter power usage, the cargo consumption is restricted to 500 watts average and 800 watts peak. At other times, the power available is 3 kw average and 6 kw peak. This power will be available on a time-sharing basis with the orbiter subsystems.

  NOTE: This power allowance is for both the Agena and the payload and must therefore be allocated according to need and usage.

4.2.3.4 Electrical Power Interface. Standardized connectors will be provided at the cargo bay interface panels to provide power for both the Agena and payload, as well as any other mission-peculiar equipment located in the cargo bay. Conditioning of the orbiter-supplied electrical power for the Agena is an Agena responsibility and will be accomplished at the interface panel. Remotely controlled disconnect capability will be required at the Agena electrical umbilical connection.

4.2.3.5 Grounding and Protection. The electrical system must be capable of equalizing the ground potential between the orbiter and the Agena before interconnection of electrical circuits. Automatic overload protection and short circuit protection must be included.

4.2.4 Guidance and Control

4.2.4.1 Capability. The Agena guidance system must be capable of controlling the vehicle flight operation from deployment on shuttle orbit until the mission is completed. It must also be capable of performing other functions, such as automatic checkout and health status monitoring.

4.2.4.2 Configuration. The guidance and control subsystem will basically consist of an inertial reference unit, guidance computer, command receiver, flight control electronics, and attitude control thrusters. A block diagram of such a system is shown in Fig. 4-12. The system may be augmented by other components, as required.

4.2.4.3 Compatibility. The Agena guidance system must operate independently of the shuttle but be compatible with the shuttle system so that information and data can be exchanged freely between the two systems.

4.2.4.4 Mission Applications. The Agena guidance system must be capable of being programmed to perform a variety of missions – earth orbit, cislunar injection, transplanetary injection, and earth orbit with return to the shuttle orbit.

Mission durations may vary from a minimum of 15 hr to a maximum of 30 days. For the long-duration mission, the system may be deactivated or operated in a passive or partially passive mode for intermittent periods as the mission requires.

4.2.4.5 Ascent Flight to Shuttle Orbit. During ascent flight to the shuttle orbit the Agena guidance system shall either be deactivated or operated in a passive mode. The Agena guidance system shall not interfere with the shuttle operation.

4.2.4.6 Command Capability. The guidance system must be capable of being commanded and updated from the orbiter command system before and after orbital deployment. These commands will be transmitted via hardline connections prior to deployment and via RF link afterward.

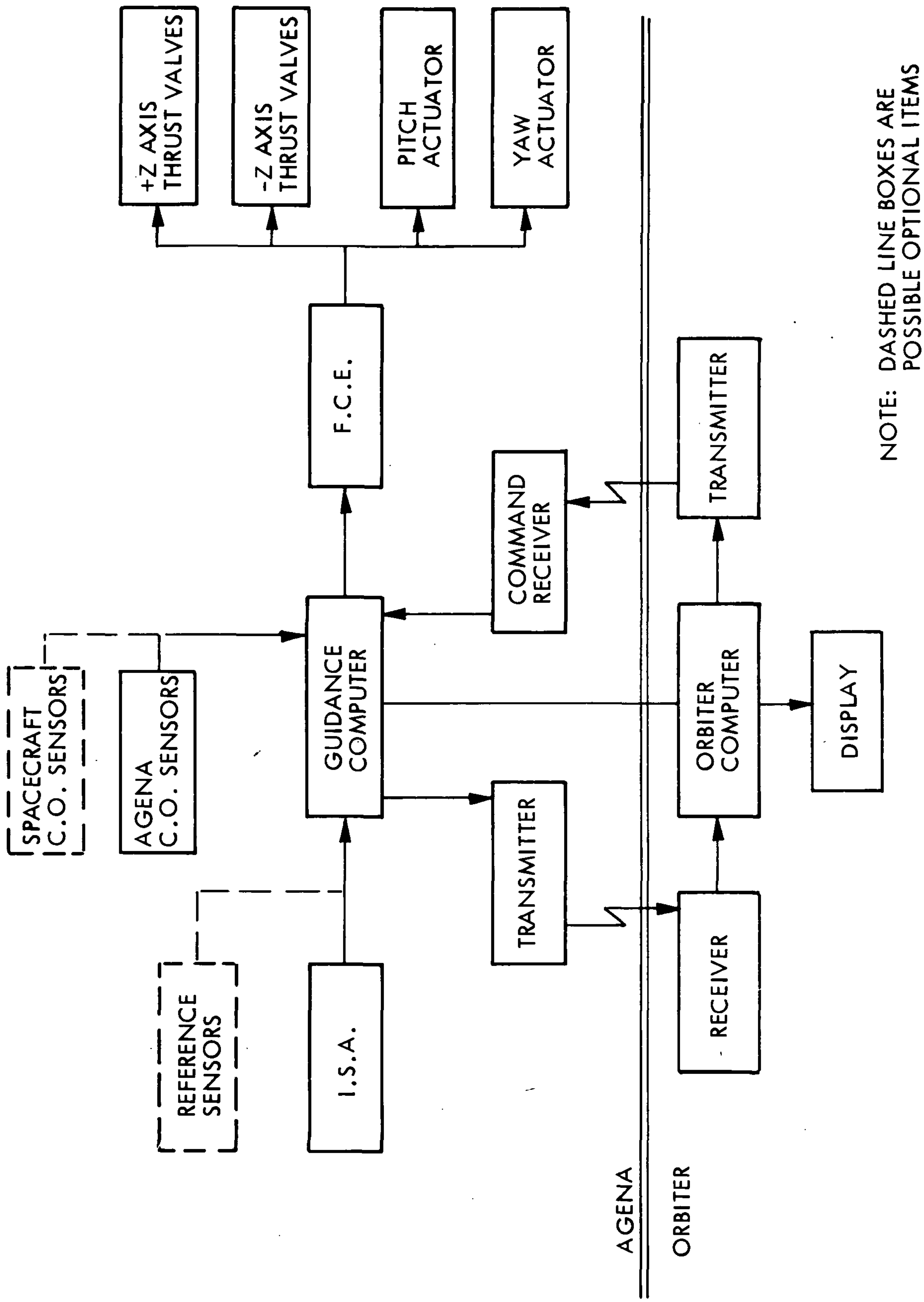


Fig. 4-12 Agena Guidance System and Key Shuttle Interconnects

4.2.4.7 Guidance Update. During shuttle orbit, the Agena guidance system must be capable of accepting input data in terms of orbit parameters, ephemerides, or state vector from the shuttle guidance system. The Agena guidance system will then determine the required ignition, data, and subsequent mission parameters.

4.2.4.8 Agena Ignition. Following Agena/payload deployment from the shuttle, the Agena guidance system must be capable of performing an automatic countdown procedure and the ignition sequence.

4.2.4.9 Injection Accuracy. The Agena guidance system must be capable of achieving the following accuracies at the spacecraft separation point:

	X	Y	Z	$\dot{x}$	$\dot{y}$	$\dot{z}$
Synchronous Equatorial			(TBD)			
Planetary Injection						
Low Earth Orbit						

4.2.4.10 Rendezvous Capability. For the long-duration mission, the guidance system must be capable of returning the Agena to the shuttle orbit within an altitude dispersion of ±2 nm. Phasing the Agena with the shuttle will be accomplished by proper selection of ignition time. Terminal rendezvous maneuver and docking capabilities are not to be included.

4.2.4.11 Agena Attitude Control. The Agena guidance system must be capable of controlling the attitude of the Agena/payload configuration within the following limits:

Coarse Mode	(TBD)
Narrow Mode	

4.2.4.12 Orbiter Attitude Control. The orbiter attitude control system will be capable of providing local vertical pointing (nadir) of the open cargo bay continuously for one complete orbit as follows:

Nadir	±45 deg within ±0.5 deg
Stability	0.03 deg/sec, all axes

The orbiter also has the capability of pointing the attached payload at the earth or at any celestial object for an interval of at least (TBD) hours with a stability of 0.03 deg/sec, all axes. Tracking, fine pointing, and specific target acquisition will be provided by the payload systems.

4.2.4.13 Checkout. The AGS computer will utilize an integrated test tape (ITT) to meet the Agena factory and launch site system test requirements. Selected subsystem test, computer discretes, and simulated flight subroutines from the ITT will be used to enable the AGS computer to check Agena vehicle status during on-pad, ascent, and orbit operations. Selected sections of the Agena self-check data will be available at the mission specialist display console.

4.2.5 Communications

After deployment, command and operation of the Agena and its attached payload will be transferred to the ground although limited command and data relay capability will be available from the orbiter. For missions such as the sun-synchronous mission in which the payload is to be returned to the orbiter, control of the Agena may be transferred back to the orbiter at some suitable handover point.

4.2.5.1 Compatibility With Orbiter. The Agena communication system may receive command data and discretes and may transmit command verifications and status data to the orbiter. It must therefore be compatible with the orbiter system with respect to data handling equipment.

4.2.5.2 Compatibility With Ground Equipment. For long-duration missions, the Agena communication system will receive commands and transmit command confirmation and status data directly to the ground control station. The Agena communication system must therefore also be compatible with the ground support equipment.

At periods of occultation, either the orbiter or the ground stations may act as a relay station between the other two communication points.

4.2.5.3 Transmission Distance. The maximum transmission distance is presently anticipated to be from synchronous altitude to ground – approximately 20,000 nm.

4.2.5.4 Communication Interface. Standardized connectors are provided in the orbiter cargo bay to interface wideband and digital data via hardline from the cargo to the orbiter communication system. Wiring from the interface panel to the Agena is an Agena responsibility.

4.2.5.5 Uplink Communication. Uplink communication from the ground (commands, data, etc.) is received by the orbiter uplink system and relayed to the Agena/payload via the data bus prior to deployment and via RF after deployment, up to a range of (TBD) nm. Commands originated by the orbiter will be transmitted to the Agena by the same means.

4.2.5.6 Downlink Communication.

a. Predeployment

(1) Digital data. Digital data can be transferred from the Agena and the payload to the ground station at a rate of:

- 25 kbps minimum allocation via the data bus
- 256 kbps via hardwire to the orbiter telemetry encoder

This capability is time-shared with the orbiter high-rate downlink data.

(2) Wideband data. Hardwired input to the orbiter wideband transmitter carrier is provided. This transmitter must be time-shared among the orbiter downlink, television, Agena/payload analog data or digital data.

For analog data, the Agena must provide commutation and a subcarrier oscillator compatible with the orbiter transmitter circuitry.

For digital data, the Agena must provide the required encoding for compatibility with the orbiter transmitter.

b. Postdeployment. After deployment from the orbiter, digital data at a rate of 25 kbps including command configuration (up to a range of TBD nm) may be relayed to the ground via RF.

4.2.5.7 Orbiter Communication Equipment. The orbiter will utilize both unified S-band (USBE) and VHF/FM communication equipment. Both systems may be used for digital data transmission and relaying. Wideband data transmission is on S-band. Schematic diagrams of the orbiter communication equipment are shown in Figs. 4-13 and 4-14.

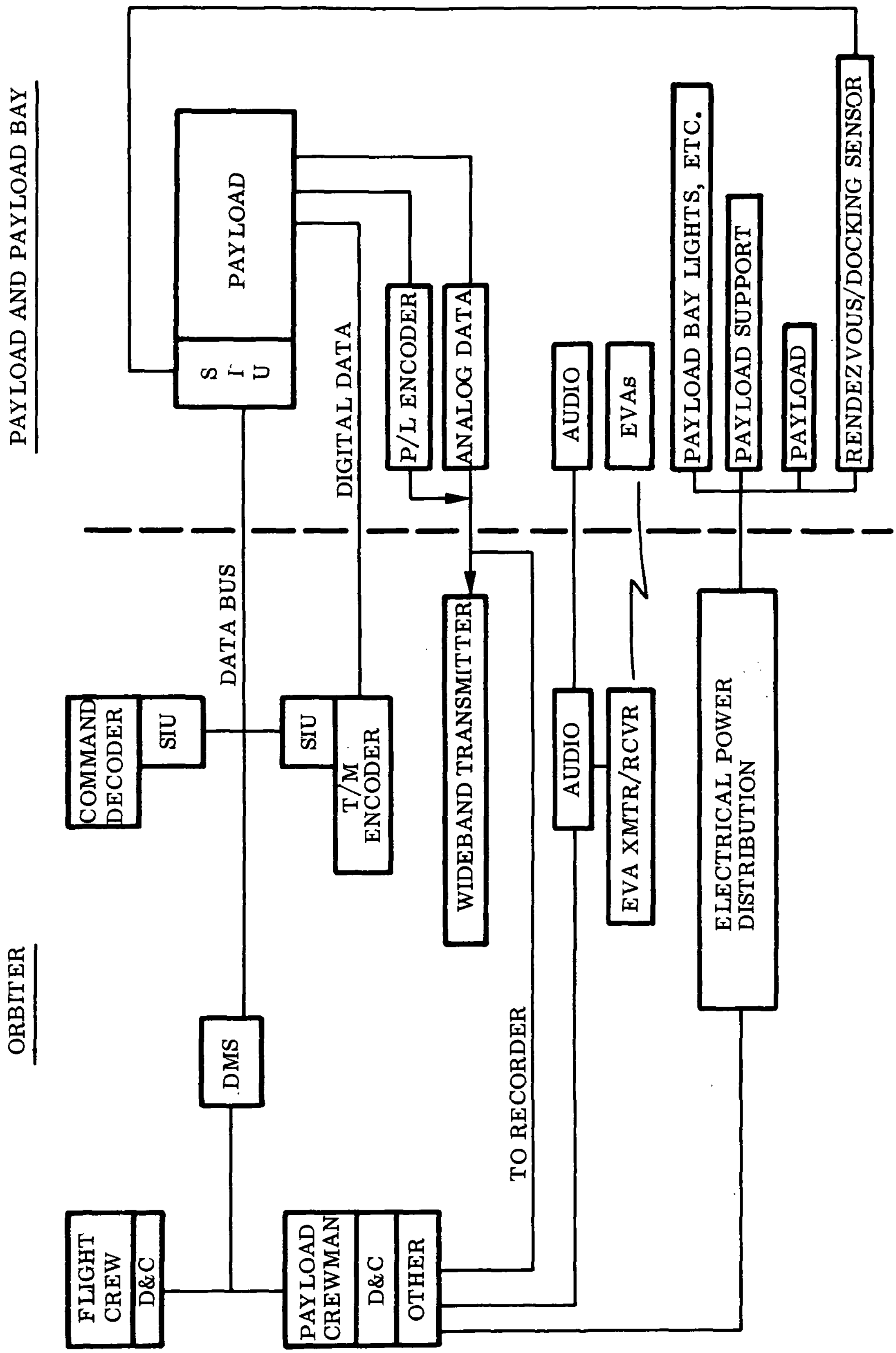


Fig. 4-13 Orbiter/Attached Payload Electrical Interface

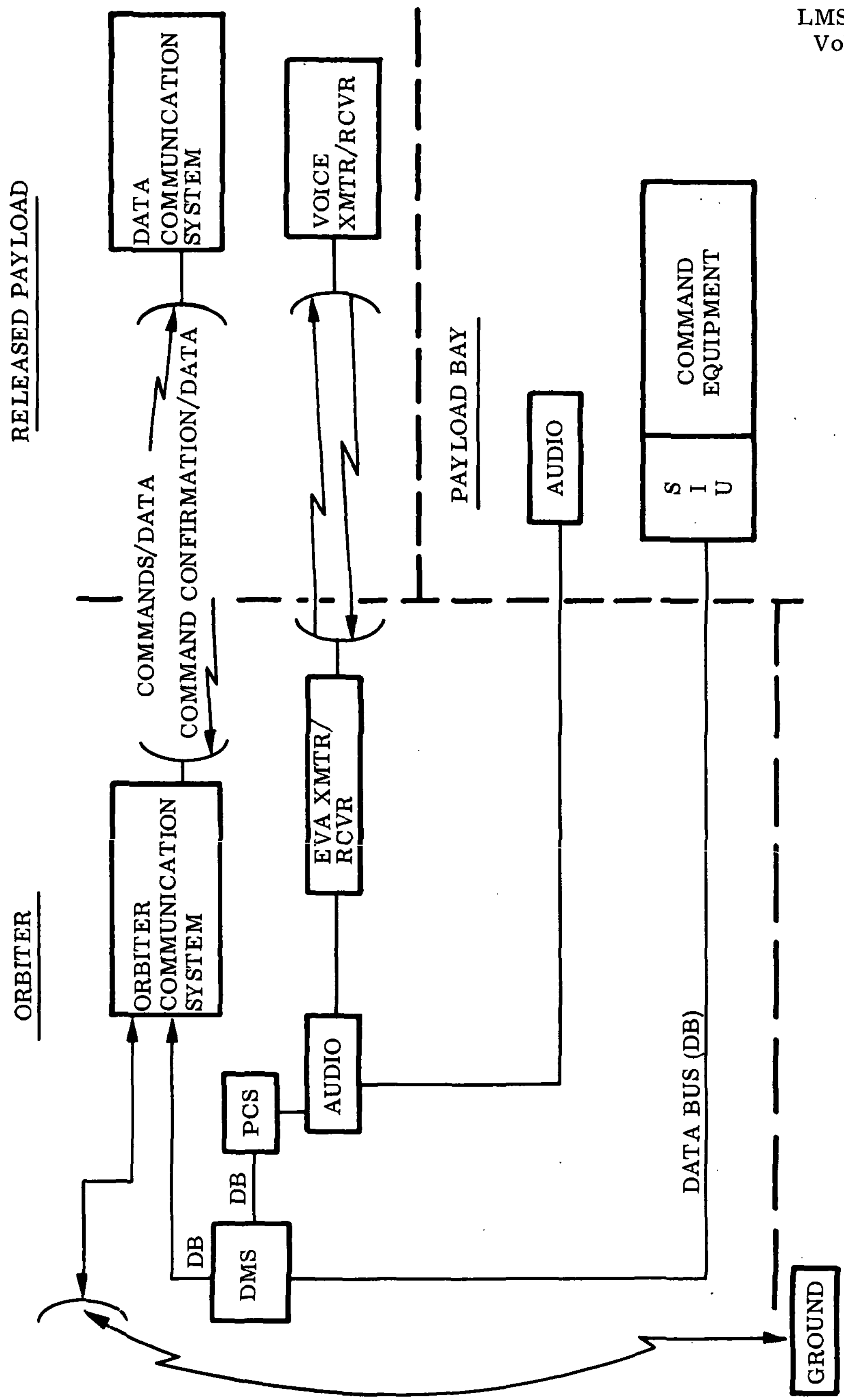


Fig. 4-14 Orbiter/Released Payload Electrical Interface

4.2.5.8 Antennas. In addition to the downlink antenna, the Agena must contain an omnidirectional antenna with the capability of maintaining continuous coverage with the orbiter regardless of look-angle between the orbiter and the Agena for a (TBD) range.

4.2.5.9 Orbiter Display and Control. The orbiter provides the capability to display mission-critical payload parameters to the flight crew on the orbiter commander's and pilot's general-purpose CRTs and to the mission specialist. A data management system keyboard is provided at the mission specialist station for command and control of the cargo through the data management system. Cargo-induced flight safety parameters must be made available to the flight crew.

4.2.5.10 Mission Specialist Station. The cargo monitoring console located at the mission specialist station is shown in Fig. 4-15. This console has the capability of recording and displaying all cargo checkout and monitoring information. Special equipment required in this console may be chargeable to the cargo.

4.2.6 Propulsion System

The Agena propulsion system must be designed to perform a variety of missions, ranging in requirement from single-burn maneuvers to multi-burn applications with varying-length burns occurring over extended periods.

4.2.6.1 Propellants. For the propulsion system, only earth-storable propellants, basically of the same type as presently used, are to be considered. Performance will be based on the currently available specific impulse of 290.8 sec, but the anticipated capability of 310 sec for the 1975–1978 period will also be considered for performance evaluations.

4.2.6.2 Restart Capability. The propulsion system must be designed for a minimum of 15 restarts. It must be capable of satisfactory start and shutdown characteristics for a minimum impulse of (TBD) lb-sec and for a maximum burning period of (TBD) sec.

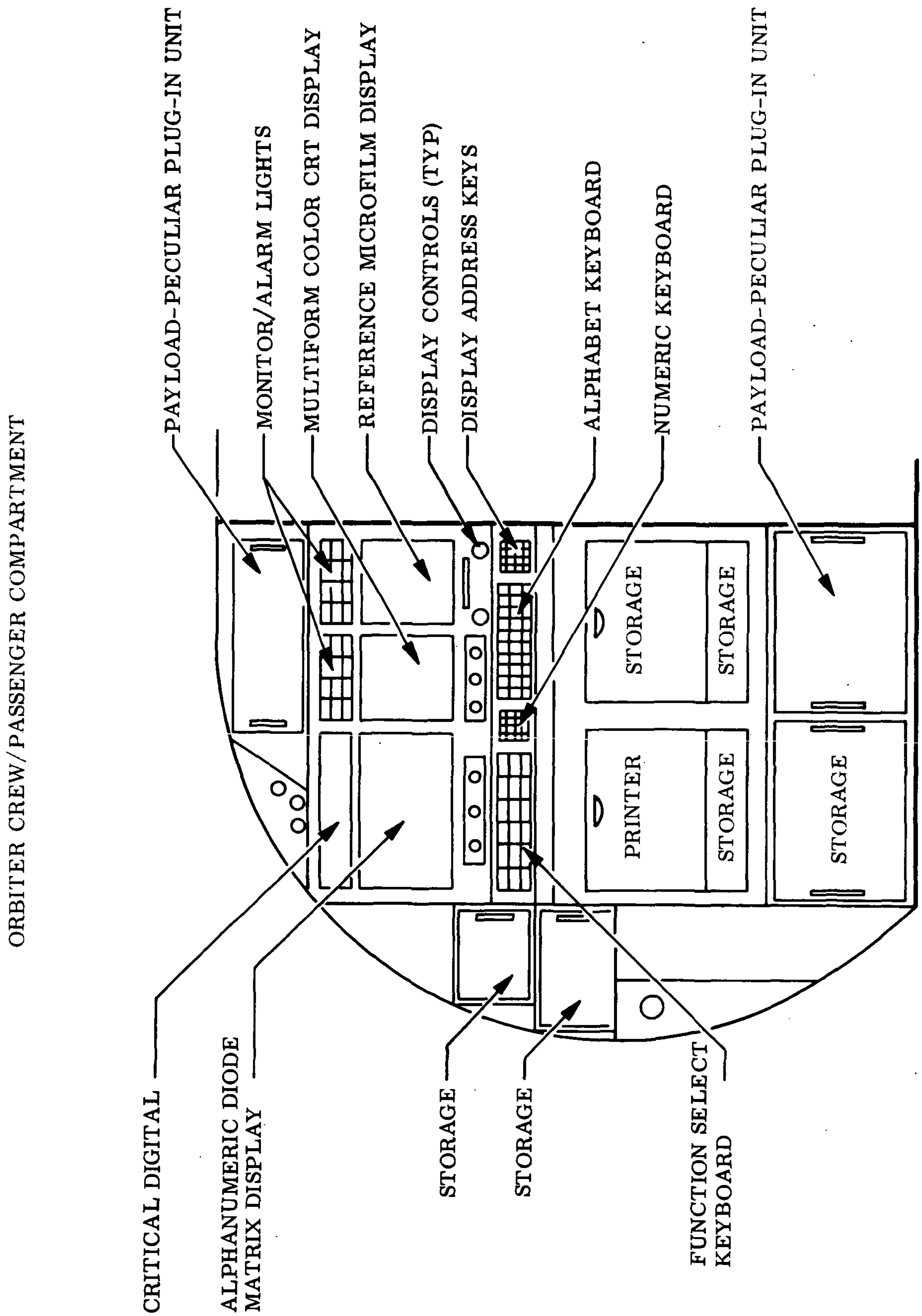


Fig. 4-15 Orbiter Payload Monitoring Console

4.2.6.3 Mission Duration. The propulsion system must be designed for at least 30 days of space storability between two successive starts. All individual parts of the propulsion system, seals, valves, PIVs, etc. must comply with this requirement.

4.2.6.4 Tanking. The propulsion system must be capable of being tanked either prior to or after installation in the shuttle cargo bay.

a. Prior to Installation (Up to 2 Weeks). The tanking will be performed with the Agena in a vertical position; subsequent to tanking, the Agena may be rotated and loaded into the shuttle in a horizontal attitude.
b. After Installation. The Agena tanking will be performed after the shuttle has been erected and with the cargo bay doors closed.

4.2.6.5 Handling. The propulsion system must be designed, so that the Agena can be removed and replaced with the tanks fully loaded.

4.2.6.6 Propellant Dump. The propulsion system must be designed so that for an abort condition the propellant can be dumped within (TBD) minutes under orbital conditions and within (TBD) minutes on the launch pad.

4.2.6.7 Instrumentation. The propulsion system must contain adequate instrumentation to monitor system health and safety. Fuel/oxidizer tank pressure, differential tank pressure, leak detectors, tank temperatures, etc., must be monitored. Redundant sensors will be used as required on critical parameters to satisfy safety criteria.

4.2.7 Environmental Constraints

4.2.7.1 Load Factors. The Agena vehicle, the attachment system, and the Agena/payload adapter must be designed to comply with the load factors specified in Table 4-4.

Entry, flyback, and landing conditions will apply only to an abort case; however, for safety reasons the integrity of the Agena system must also be investigated for these flight conditions. All the propellants must be dumped prior to reentry.

Table 4-4

PRELIMINARY LOAD FACTORS FOR ORBITER PAYLOAD
(STEADY-STATE)

Condition	N_x (g)	N_y (g)	N_z (g)
Launch	1.5	±0.5	-0.5
High Q (Booster Thrust)	1.9	±0.5	±0.6
End Boost (Booster Thrust)	3.3	±0.2	-0.6
End Burn (Orbiter Thrust)	3.3	±0.5	-0.5
Entry	-0.5	±1.0	-2.0
Flyback	-0.5	±1.0	+1.0 -2.5
Landing	-1.3	±0.5	-2.7

Following deployment on orbit, the Agena and payload will experience an axial load factor that will be a function of time and payload weight. For lightweight spacecraft, this axial load could be on the order of 5 to 6 g at the end of the Agena engine operating phase.

4.2.7.2 Atmospheric Environment. On the launch pad, the orbiter cargo bay is capable of atmospheric control independent of the orbiter internal structure. This provision allows for the control of temperature, humidity, atmospheric composition, and particle contamination. The ground support equipment and connections for the GSE are to be the responsibility of the Agena.

The orbiter cargo bay will be vented during launch, ascent, and reentry phases and unpressurized during the orbital phase of the mission. Typical pressure environment curves are shown in Fig. 4-16. Agena cavities and closed boxes must be designed for these pressure conditions.

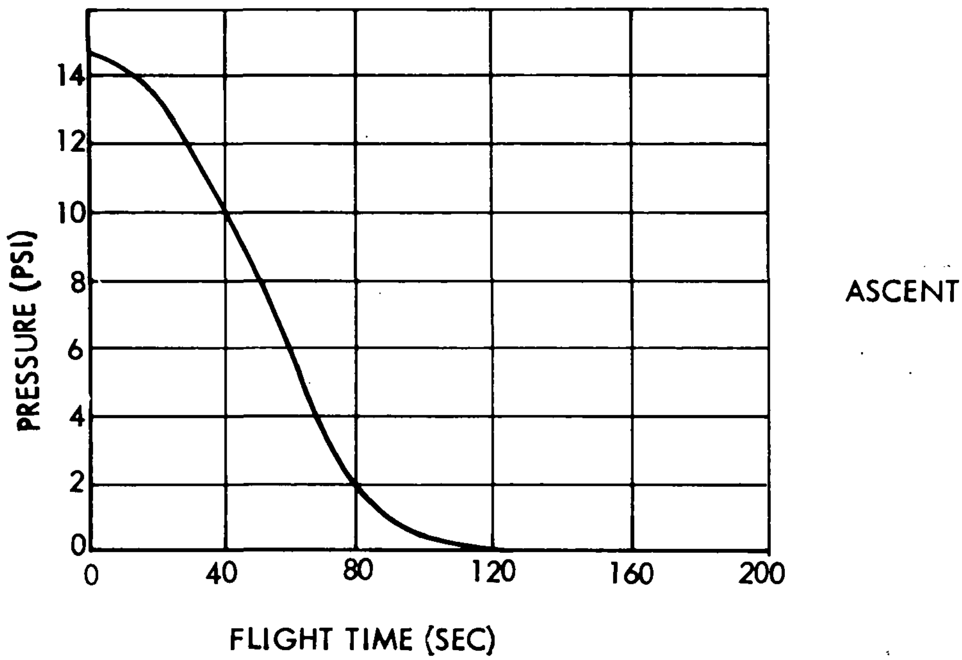
Atmospheric contamination in the cargo bay area will be minimized by controlled venting of orbiter subsystems and location of subsystem vents to prevent direct plume impingement in the cargo area. Additionally, material control is enforced to minimize outgassing in the cargo bay and its immediate surroundings. The Agena subsystems must be designed so that they do not contribute to the contamination level inside the cargo bay.

4.2.7.3 Thermal Environment. The anticipated cargo bay wall temperature limits during launch and reentry are shown in Figs. 4-17 and 4-18. The effect of the these environmental conditions upon the Agena subsystems, especially the avionic and propulsion systems, must be evaluated; if required, compensating provisions such as insulation or an active thermal control system must be designed.

A nominal amount of heating or cooling will be available to the cargo bay from the orbiter thermal control system. The minimum heat transfer capacity dedicated to the cargo is as follows:

a. Nominal capacity, 3500 Btu/hr b. Peak capacity, 5200 Btu/hr

This heat exchanger must be capable of operating from zero to maximum capacity with no restriction on operating time. Thermal control in excess of this capability will be chargeable to the Agena system.



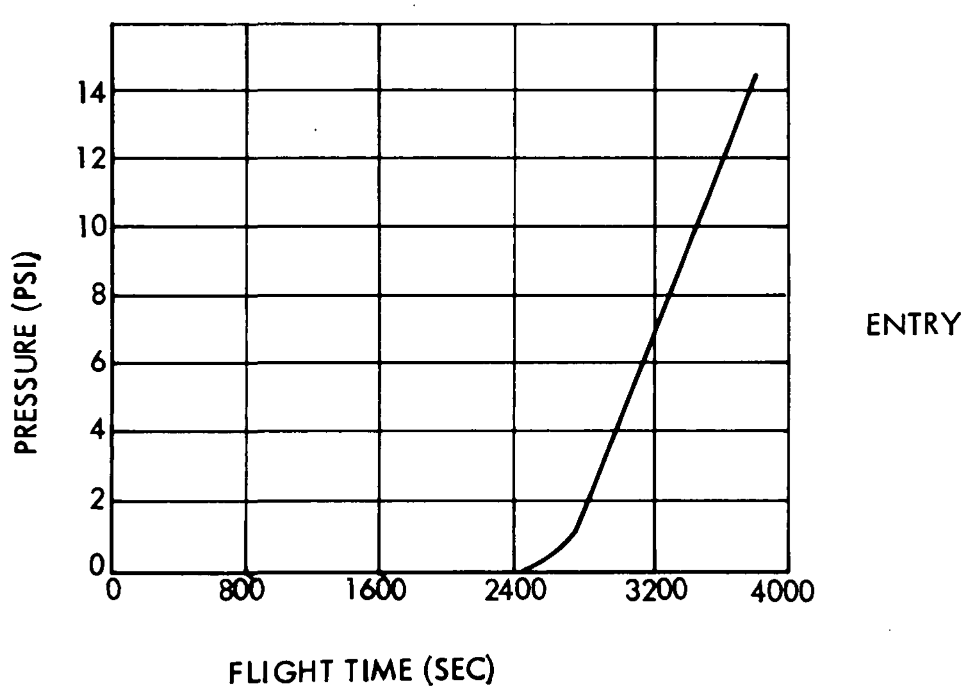


Fig. 4-16 Cargo Bay Internal Pressure Time Histories

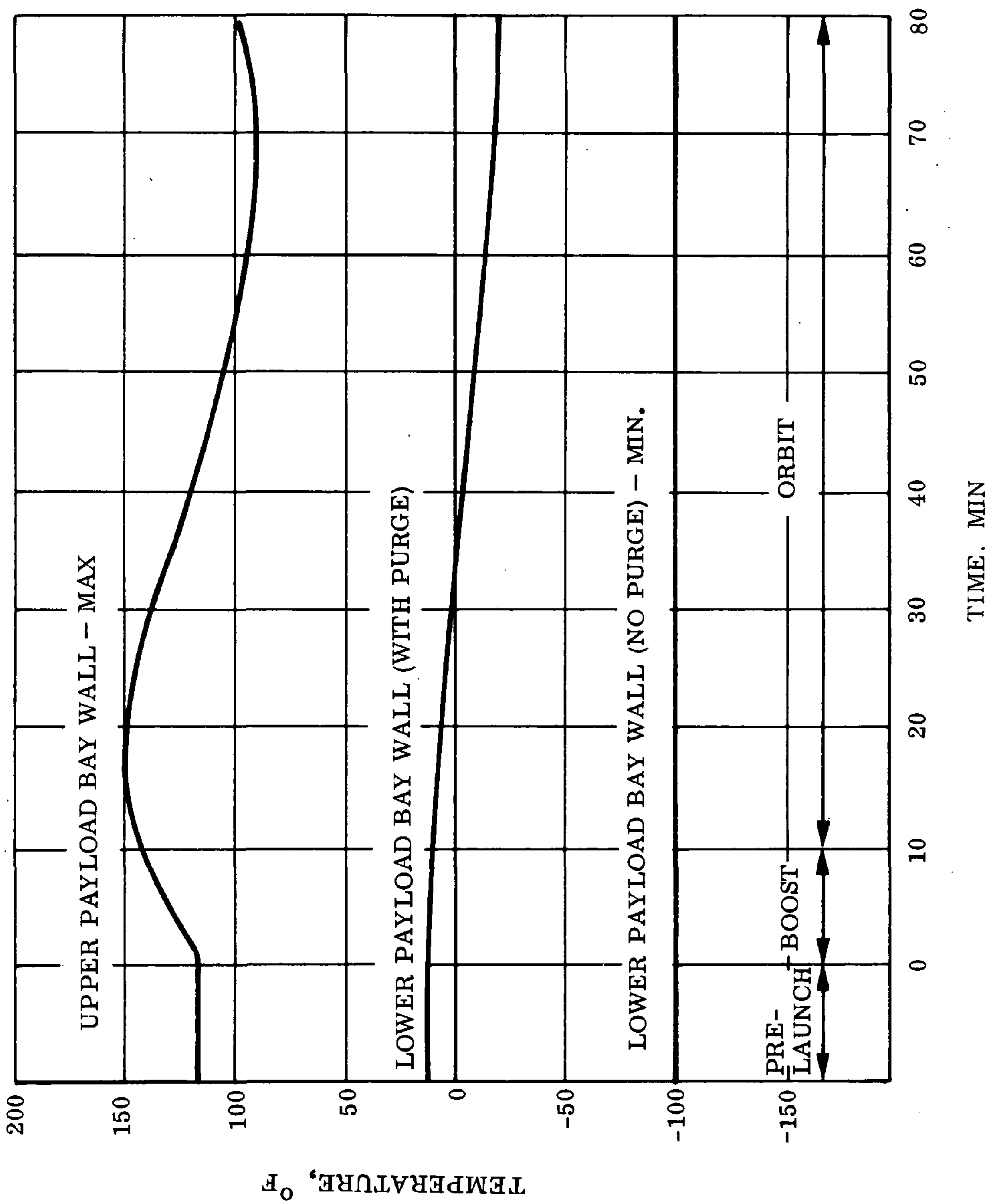


Fig. 4-17 Typical Payload Bay Wall Launch Temperature Limits

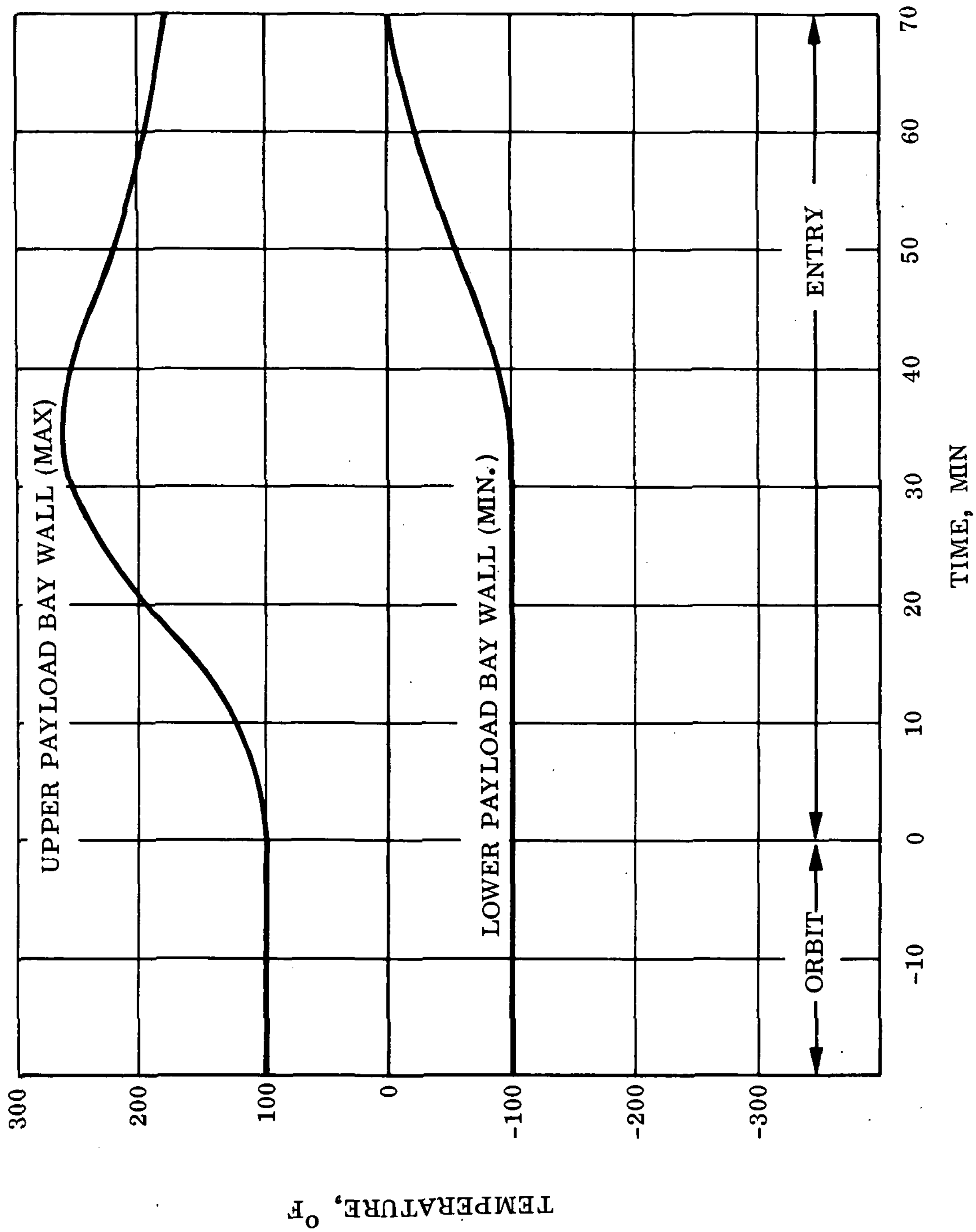


Fig. 4-18 Typical Payload Bay Wall Entry Temperature Limits

4.2.7.4 Dynamic Environment. The random vibration associated with the dynamic environment is predicted to stay within the limits shown in Fig. 4-19, which gives the level of acceleration as a function of frequency. Sinusoidal vibration resulting from low-frequency dynamics has not yet been determined.

A maximum acoustic noise level of 160 dB is anticipated external to the cargo bay at liftoff. This noise is generated primarily by the booster main engines and transmitted through the air to the payload bay. Following liftoff, the acoustic noise from the engines is expected to decrease as the distance between the launch vehicle and the ground increases. However, the vehicle will pass through another fluctuating pressure area during the transonic and entry phases of the mission. The acoustic levels are anticipated to be within the levels shown in Fig. 4-20.

The Agena subsystems must be designed to comply with these requirements. If the Agena requires a dynamic environment less severe than the above specifications, the Agena must provide the required equipment in terms of baffles, isolation, or vibration damping to obtain the desired dynamic level. This equipment will be chargeable to the Agena.

4.2.7.5 Electromagnetic Compatibility. The Agena and its associated subsystems and equipment must be designed to be compatible with the requirements specified in the Electromagnetic Interface Control document (TBD).

4.2.8 Safety Requirements

4.2.8.1 Cargo Bay Vent. The orbiter cargo bay will be unpressurized and will have provision for venting and purging as required.

4.2.8.2 Instrumentation. The Agena vehicle system must be equipped with sufficient instrumentation, sensors, and monitoring equipment to satisfy the safety instrumentation requirements. This instrumentation may include pressure gages, temperature gages, leak detectors, voltmeters and ammeters, etc.

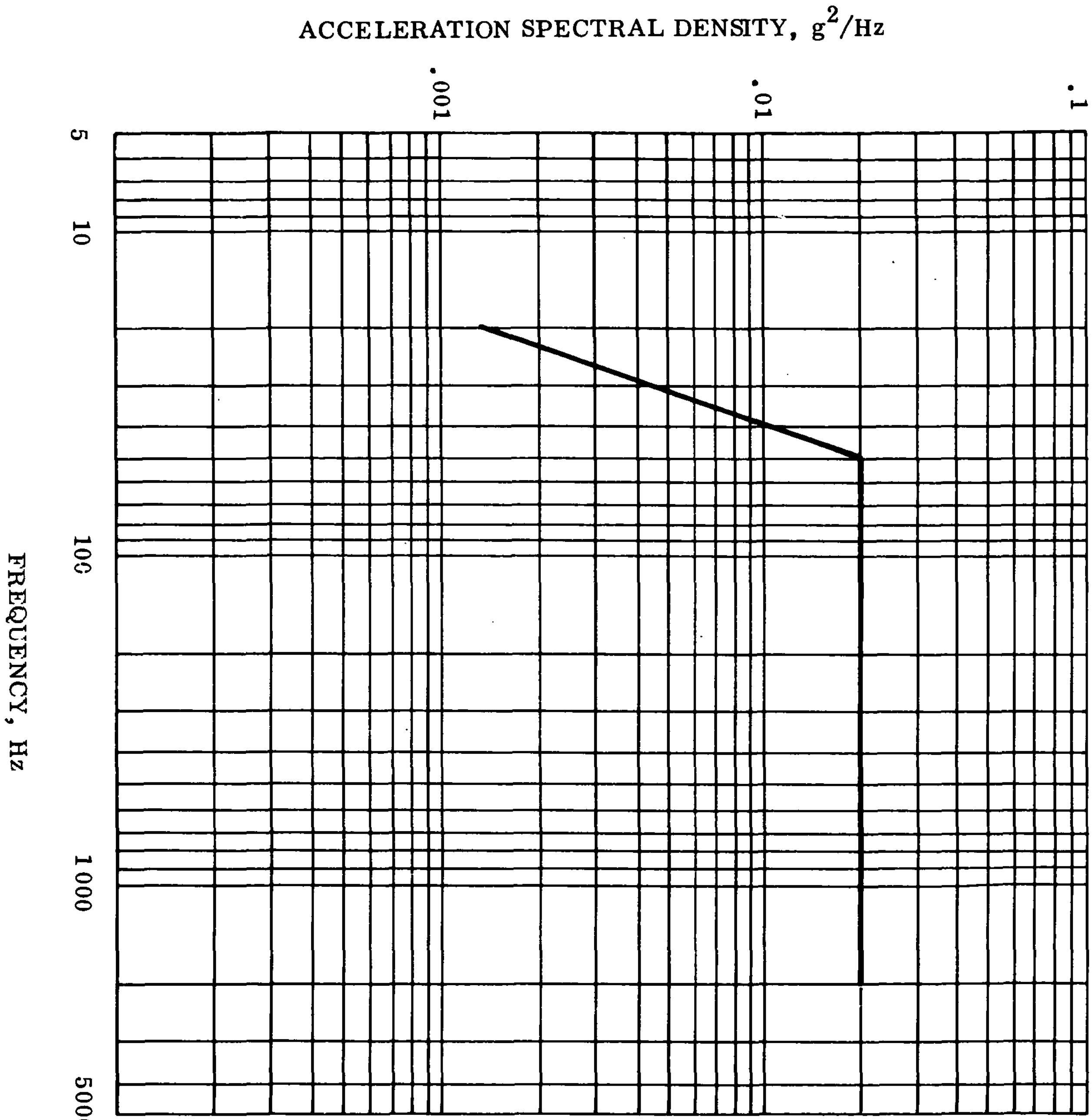


Fig. 4-19 Orbiter Payload Bay Vibration Environment

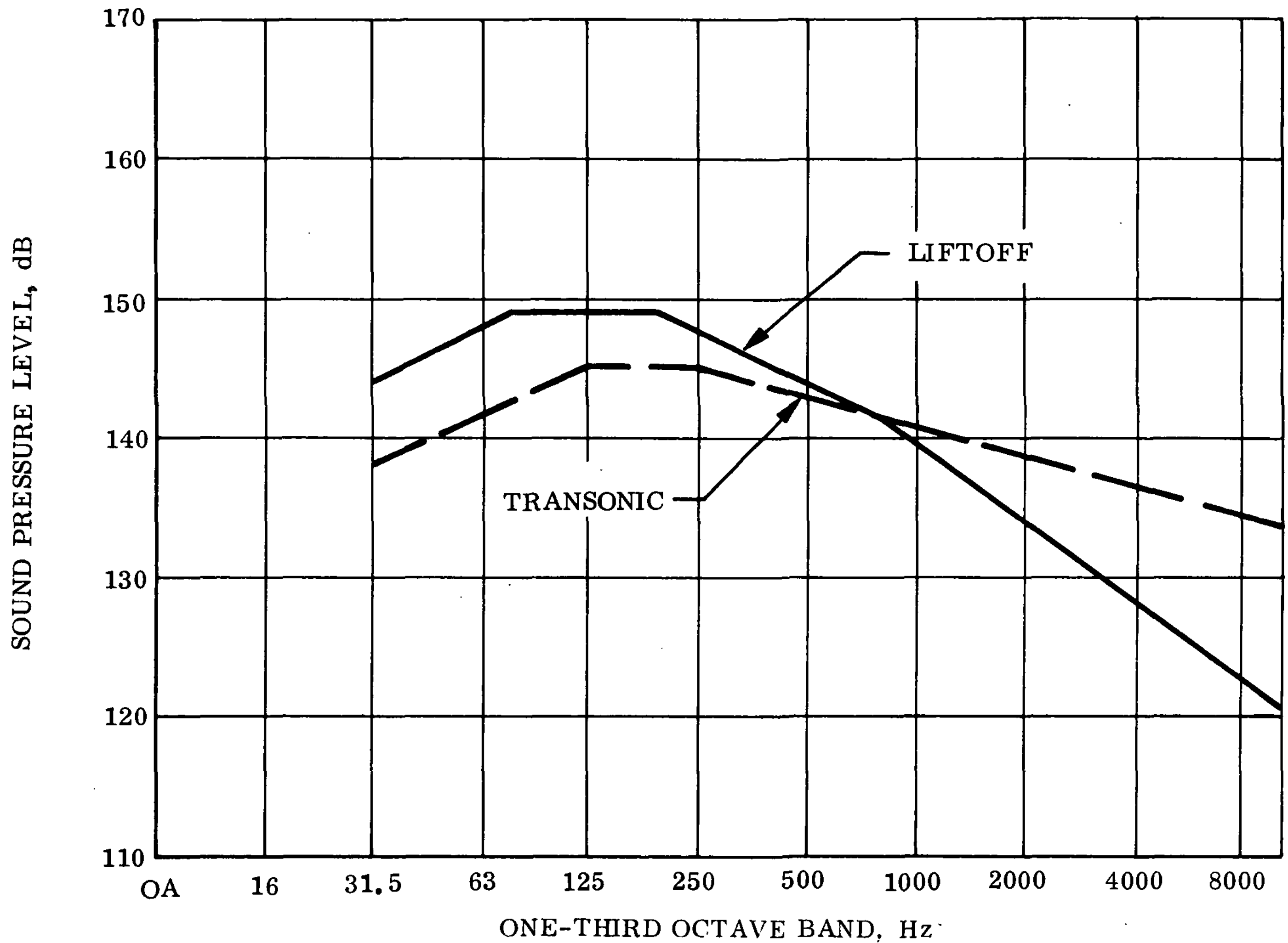


Fig. 4-20 Acoustic Noise Spectrum

The Agena system must be continuously or intermittently monitored with respect to safety critical parameters from the Agena tanking and pressurization operations until deployment from the orbiter. The same system may also be used for health status reports and diagnostic data during Agena flight.

4.2.8.3 Propellant Dump. The Agena must be designed so that the propellant can be dumped within a period of (TBD) sec in case of a flight abort condition. Propellant dumping must be possible under orbital conditions and must be accomplished either simultaneously or sequentially as safety considerations require.

Provisions for propellant dump, such as plumbing, valves, fittings and connections from the Agena to the orbiter service panel, are the responsibility of the Agena and are chargeable to the Agena system.

Provision for dumping Agena propellant must not produce any adverse effect upon the orbiter stability and control. This criterion must be fulfilled for any flight condition.

As a backup safety provision, complete jettison of the Agena/payload configuration may be considered.

4.2.8.4 Structural Integrity. The Agena structural integrity must be investigated for a safety factor of 1.5 for the loading conditions that will occur when the Agena is mounted in the orbiter cargo bay. This evaluation must consider the following cases:

a. Propellant tanks loaded, unpressurized
b. Propellant tanks loaded, pressurized
c. Propellant dumped

The propellant tanks and pressure vessels must conform to the following criteria for all temperatures at which the tanks will be pressurized:

a. Proof pressure, 1.05 x (operating pressure); pressure vessels, 1.5
b. Burst pressure, 1.5 x (operating pressure); pressure vessels, 2.0

Other components, such as pipes, valves, fittings, and connectors, must have a burst pressure rating of at least 2.5 x (operating pressure).

4.2.8.5 Pyrotechnic Devices. All pyrotechnic devices must be properly protected to prevent electromagnetic and electrostatic hazards. All electric wires must be properly shielded and all components grounded.

4.2.8.6 Electrical Systems. All electrical systems must be designed with automatic overload and short-circuit protection. Provisions to equalize ground potential between the orbiter and the Agena before interconnection of electrical circuits must be included.

4.2.8.7 Hazardous Material. Agena elements containing hazardous materials must have self-contained provisions to protect the orbiter against any Agena-generated potential hazards

4.2.9 Operations

4.2.9.1 Shuttle Ground Time. Normal shuttle turnaround time from landing to launch will be approximately 2 weeks.

4.2.9.2 Agena/Payload Checkout. Agena/payload mating and checkout must be completed prior to installation in the orbiter cargo bay.

4.2.9.3 Agena/Payload Installation. The Agena/payload will normally be loaded and offloaded with the orbiter in a horizontal position; however, the design must not prohibit emergency cargo access, removal, or loading in the vertical position.

4.2.9.4 Agena Replacement. Removal and replacement of the payload or the Agena/payload combination must be accomplished within 10 hours elapsed time and must be completed at least 2 hours before launch.

4.2.9.5 Access to Agena on the Pad. Pad access to the Agena/payload is normally not to be required. For limited operations agreed upon as essential, access will be limited to those items directly accessible through the orbiter crew compartment or the cargo bay access panels.

4.2.9.6 Repair and Maintenance. In-flight maintenance and repair of the Agena/payload must be limited to, and accomplished by, Agena-supplied module replacements only.

4.2.10 Ground Support Equipment

It is anticipated that all Agena ground support equipment (GSE) will be limited to pre-installation equipment required for Agena/payload mating and checkout and handling. After installation, all connections such as electrical power, communication, propellant dump lines, etc. will be through the cargo bay service panels.

4.2.10.1 Cargo Bay Service Panels. Cargo bay service panels are provided in the orbiter structure for interface access to the Agena/payload. These normally blank nonstructural access panels are capable of being replaced with payload-peculiar panels designed to service a particular payload. The weight difference between the blank service panels and the payload-peculiar panel will be charged against the cargo weight.

4.2.10.2 Agena/Payload Mating. The payload may be mated to the Agena in either the vertical or horizontal attitude. All Agena operations prior to this phase are independent of either shuttle or payload operations. After this mating has been completed, the Agena/payload combination is mated to the orbiter with the orbiter in the horizontal position.

For mating the Agena and payload in the horizontal position and for transporting and handling the combined Agena/payload, a support fixture will be required to avoid overloading the Agena vehicle with the cantilevered weight of the payload. This support fixture can utilize part of the orbiter payload bay adapter (for supporting the Agena/payload in flight). A transporter will then be required to carry the combined Agena/payload/support fixture to the shuttle installation area.

4.2.10.3 Shuttle Maintenance and Checkout Facility (MCF). After the Agena is installed in the orbiter, its power is supplied via the cargo bay service panels.

Air conditioning and/or environmental control of the payload bay will be provided by the shuttle. Upon completion of Agena post-installation checkout, all monitoring of the Agena will be through the shuttle onboard data management system. There will be no GSE electrical power, control, or instrumentation to the Agena.

4.2.10.4 Shuttle Vertical Assembly Building. No Agena GSE will be required. The shuttle will provide payload bay conditioning, power, and safety monitoring. The Agena will perform its own health checks, if required.

4.2.10.5 Launch Pad.

Guidance Optical Alignment. For certain missions, it may be necessary to determine the Agena azimuth orientation with a high degree of accuracy prior to liftoff. For these flights, an external optical alignment device mounted on the launch tower will be required. The optical alignment will be performed at launch minus 30 minutes. The alignment beam can be introduced either through the open cargo bay door or through a small window in the door.

Agena Propellant Dump. The requirement to provide Agena propellant dump capability in the event of an abort situation on the pad will require GSE in the form of umbilical disconnects, propellant lines, and receiver tanks. Provisions for draining, flushing, and drying the GSE dump lines and tanks will also be required.

Agena/Payload Removal and Replacement. To satisfy the requirement that the Agena and/or payload be capable of removal and replacement while on the pad will require ground handling equipment capable of rotating the Agena and payload from the vertical to the horizontal position for transfer to transport dollies. If the removal includes the payload support cradle, transport dollies matching payload bay hard points will be available as GFE. Separate handling of either the Agena or payload may require special transport dollies.

Section 5

AGENA SUBSYSTEM MODIFICATION REQUIREMENTS

Section 5
AGENA SUBSYSTEM MODIFICATION REQUIREMENTS

To provide guidelines and establish the design approach defining the Agena tug configuration, the basic subsystem changes and modifications required to integrate the Agena with the Space Transportation System and to perform the space tug missions have been identified. These modifications, which are discussed by vehicle subsystem, are based on converting the Ascent Agena design (as presented in Annex A) to an Agena tug for deployment from the shuttle orbiter.

5.1 STRUCTURES

The basic Agena structure can be divided into four main sections:

1. Forward equipment section (Sta 246.50 to 287.50)
2. Tank section (Sta 287.50 to 384.00)
3. Thrust cone (Sta 384.00 to 411.86)
4. Aft equipment rack (Sta 411.86 to 462.50)

These sections are shown in Fig. 5-1.

5.1.1 Forward Equipment Section

The structural integrity of the forward equipment section will depend upon the loading conditions when the Agena/payload is installed in the orbiter cargo bay. These loading conditions will be determined by the design of the Agena/payload adapter and the weight, CG location, and suspension of the attached payload. Theoretically, the Agena should be able to carry a payload weight on the order of 50,000 lb to utilize the full capability of the shuttle for certain missions. This weight should also be combined with a payload CG location as far forward as the orbiter configuration will permit. Structural calculations show that if only the Agena is supported and the payload is cantilevered at Agena Station 246.50, the maximum allowable bending moment at Station 246.50 will impose

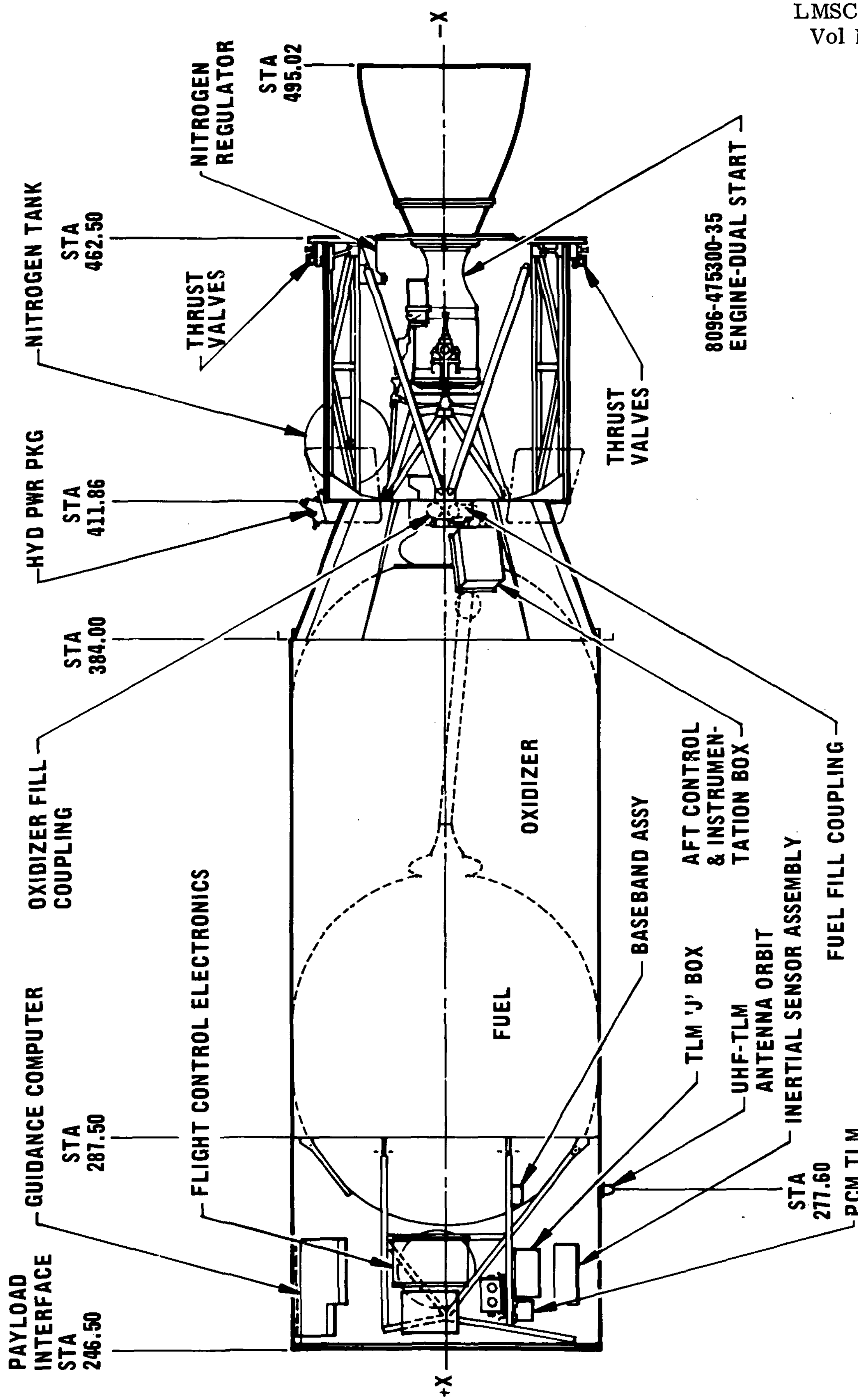


Fig. 5-1 Agena Tug Inboard Profile

a limitation on the payload CG location. This limitation is shown in Fig. 5-2 as a function of payload weight. If, however, the payload and the Agena are supported at the payload CG location and at the aft end of the Agena tank section (Station 384.00) as shown in Fig. 5-3, the bending moments can be reduced considerably (Figs. 5-4 and 5-5) and will, even for the most severe loading condition, be far below the allowable Agena limits.*

5.1.2 Tank Section

Figures 5-4 and 5-5 also show that for a proper support system the bending moment over the tank section will be significantly below the structural capability. No direct structural modifications will therefore be required to this section, with the exception of an attachment ring mounted at the aft end of the tank section at Station 384.00. This ring, which is a C-section, is mounted externally to the Agena and does not affect the internal structure. Brackets for handling by the orbiter standard deployment mechanism (manipulators) could also be incorporated with this attachment ring.

5.1.3 Thrust Cone

At present, no modifications or structural changes to this section are expected.

5.1.4 Aft Equipment Rack

Minor changes to the aft equipment rack may be required to provide bracketry for additional equipment for the mission-peculiar multistart engine and additional gas bottles. The present roller mechanism that guides the Agena out of the booster adapters can be removed.

If a larger expansion ratio nozzle is used, it may be necessary to relocate some of the structural members of the aft rack in order to accommodate the larger nozzle and

*Modification to the forward section will therefore be limited to an attachment ring that will transmit the loads from the attachment adapter to the Agena structure. The inclusion of this ring will depend upon what type of adapter is used.

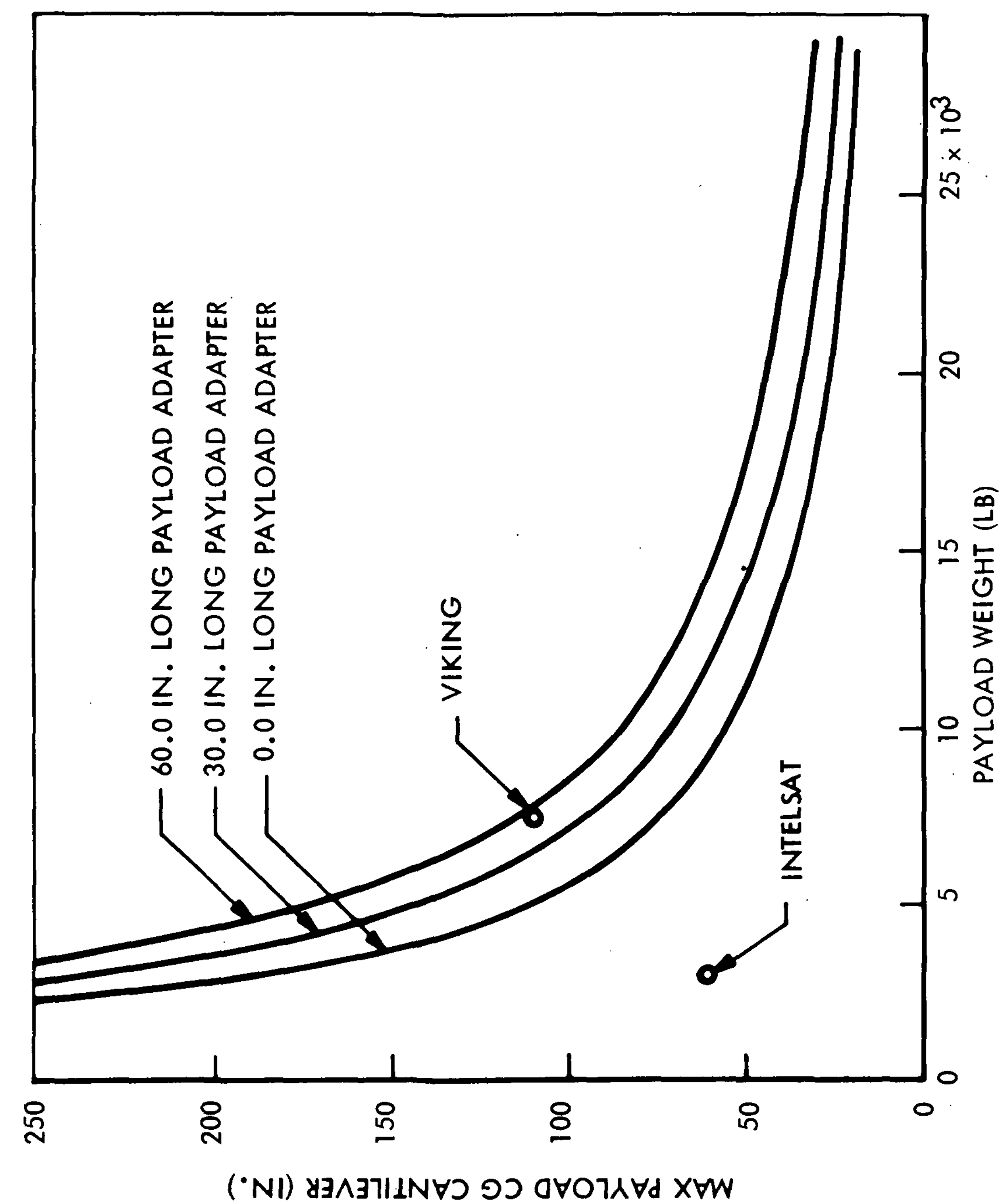


Fig. 5-2 Cantilevered Payload Limitations

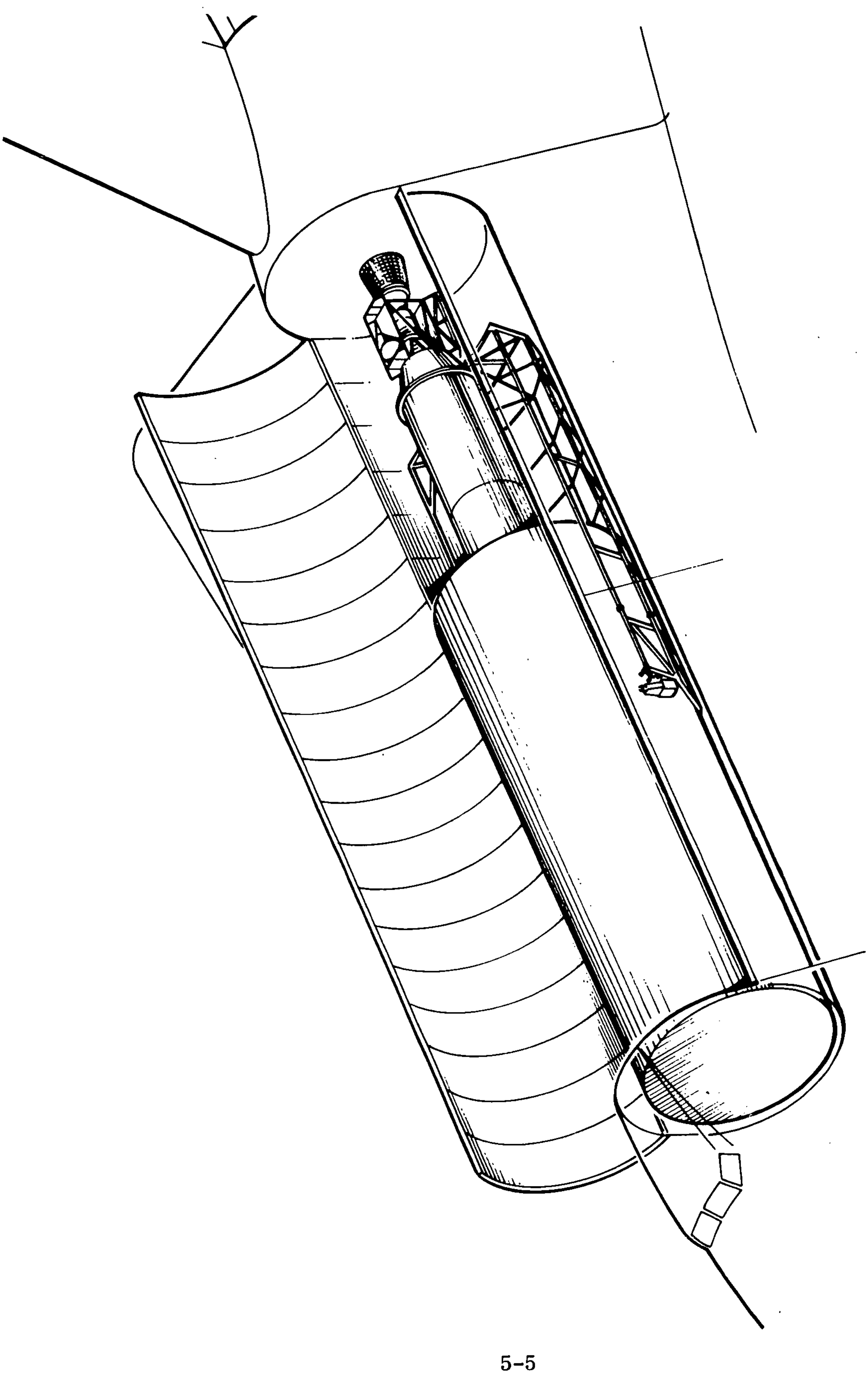


Fig. 5-3 Extended Cradle Support

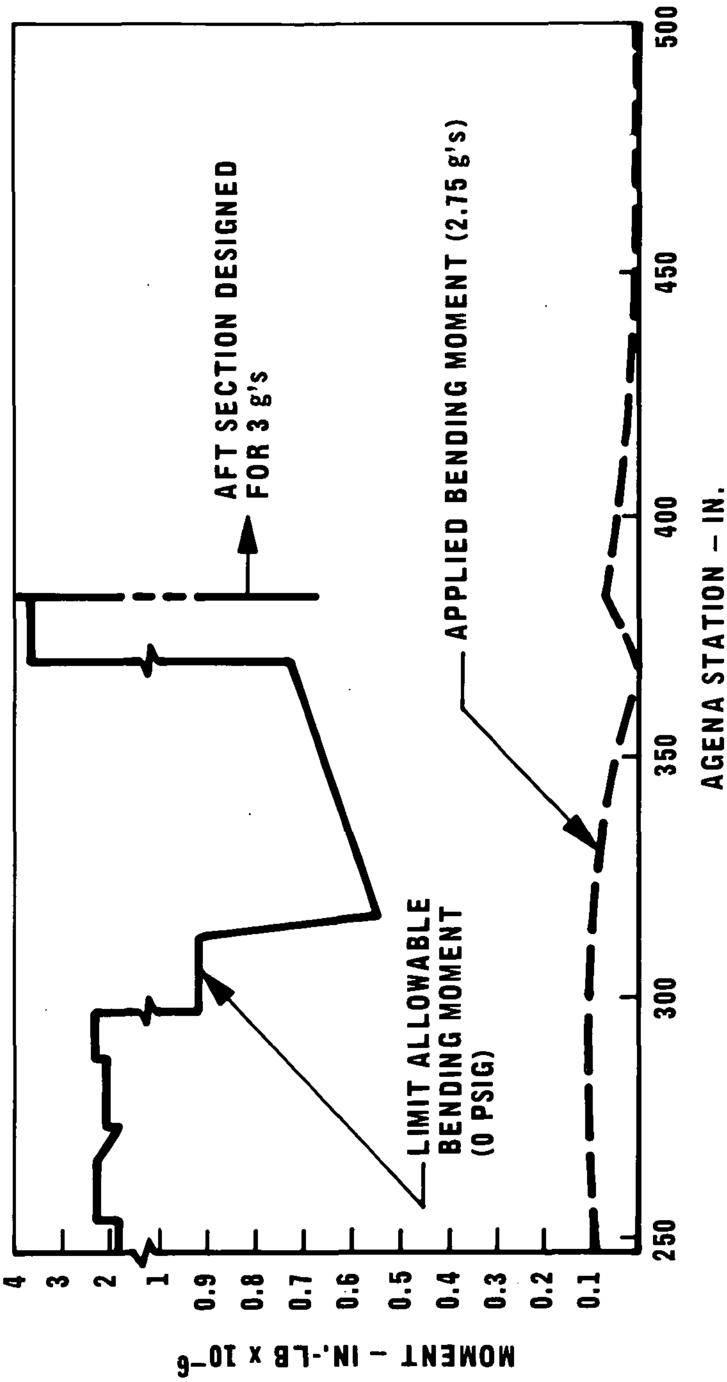


Fig. 5-4 Applied and Allowable Bending Moments – Landing

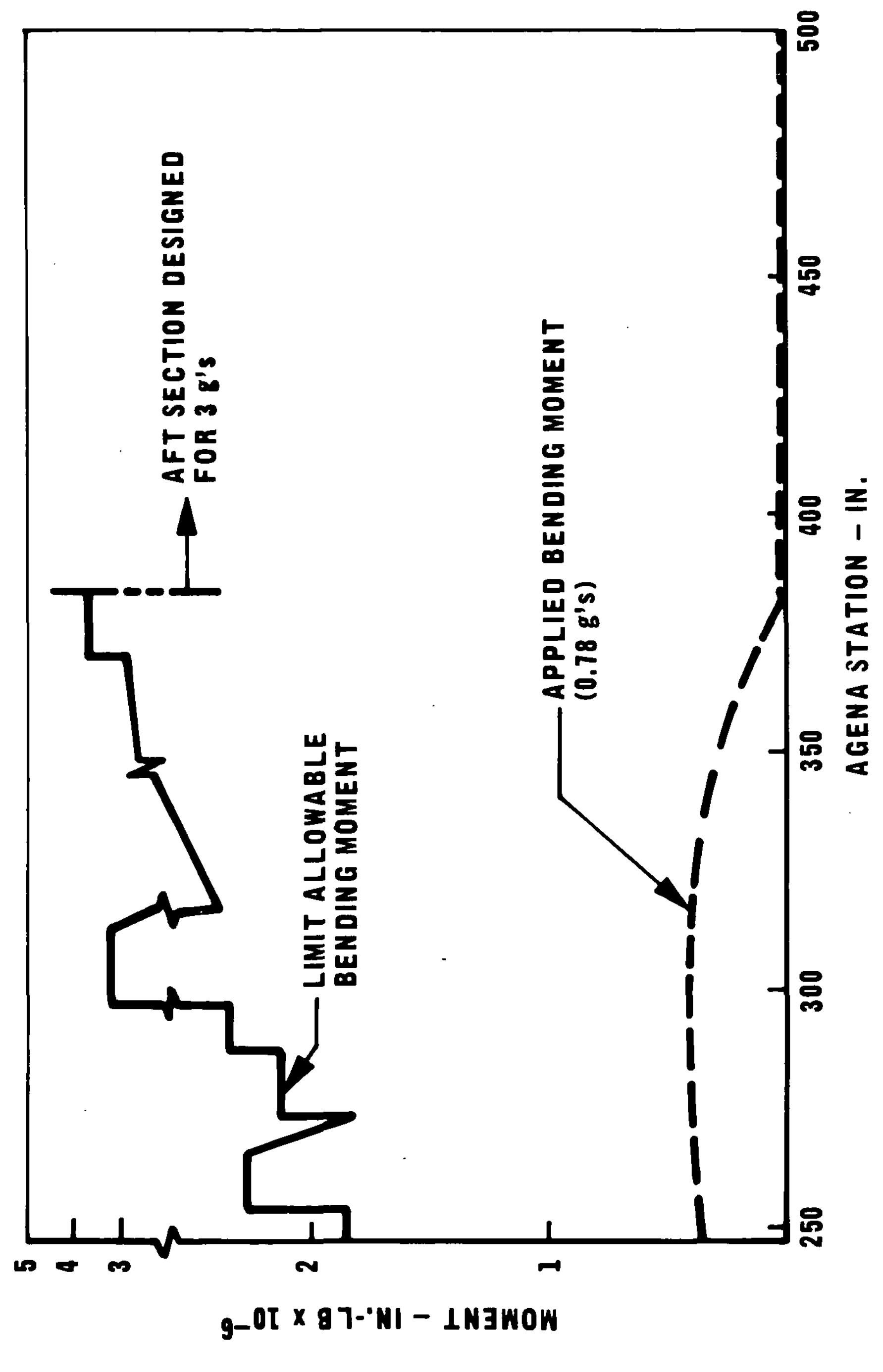


Fig. 5-5 Applied and Allowable Bending Moments – Flight (High Q)

thrust chamber. These modifications will, however, become standard configuration in that case and should not be considered as Agena modifications for the tug application.

5.2 PROPULSION

The BAC Model 8096 engine is used in the present Ascent Agena vehicle. This engine, which is capable of one, two, or three starts, uses unsymmetrical dimethylhydrazine (UDMH) and inhibited red fuming acid (IRFNA) as propellants. A schematic diagram of the propulsion system is shown in Fig. 5-6.

5.2.1 Performance

Examination of the presently available mission models indicates a large number of missions involving heavy payloads in high-energy orbits. This is especially true for synchronous-equatorial missions. The 8096 engine with a 45:1 expansion nozzle has a nominal specific impulse of 290.8 sec. An improvement program that could increase the specific impulse up to 310 sec has been initiated. This program is being considered for other Agena applications; if successful, the higher-impulse engine will become standard equipment; therefore, both I_{sp} values were used in the Agena tug performance analyses. This increase in performance can be accomplished by the following modifications to the propulsion system:

a. Substitute a -1 injector for the present injector
b. Use a higher-density acid (HDA)
c. Increase the nozzle expansion ratio

These changes to the propulsion system will not significantly affect the Agena configuration except for the nozzle extension. The use of high-density acid has already been demonstrated in flight and its performance gain verified.

5.2.2 Restart Capability

As outlined in par. 4.1, the planetary-injection mission will require one engine start. The synchronous-equatorial mission will require a minimum of two and nominally three

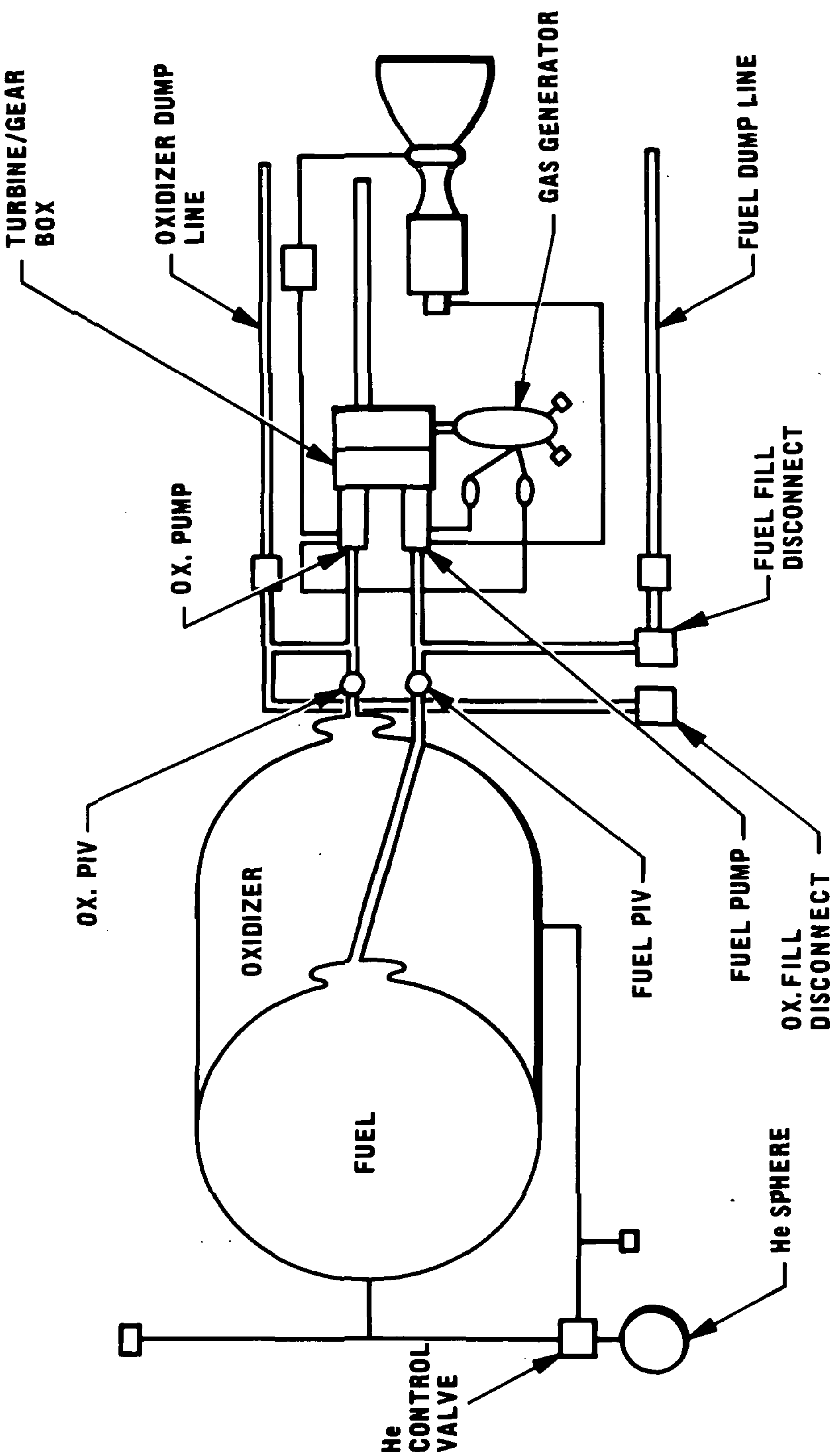


Fig. 5-6 Propulsion Schematic

starts. The sun-synchronous mission as presently defined will require a minimum of six engine starts. For the first two missions, the basic 8096 engine will be sufficient; but for the third mission, an increased start capability must be provided. This capability can be provided by adding a recharging start system similar to that developed and used for the BAC Model 8247 engine. To provide sufficient margin and to reserve some start capability for testing, a total capability of 15 starts was established as a design requirement. This requirement is compatible with the 8247 capability.

The 8247 engine is shown in Fig. 5-7, which indicates the location of the two rechargeable start tanks. The engine is started by allowing propellants from the start tanks to flow to the gas generator, where a hypergolic reaction takes place. The gas generator drives the turbine, which in turn drives the oxidizer and fuel pumps. These pumps supply the thrust chamber with propellants and, after each start, recharge the start tanks. The duration of the initial burn and subsequent restart firings may be of any desired length, providing that no engine burn duration is less than 2 sec. A schematic diagram of the 8247 start system is shown in Fig. 5-8.

This engine was flight proven on six Gemini Target Vehicle flights, one of which accomplished eleven restarts in orbit. For the Agena tug application, an 8096 engine will be modified with this start system; it may also include the performance modifications previously described. The restart modification represents a net increase in engine weight of 29 lb. Installation of this engine will require only minor changes to the aft equipment rack.

5.2.3 Operational Lifetime

The 30-day mission requirement is not expected to require modifications to the propulsion system related to propellant storage. A total elapsed time of 22 days between engine restarts has been demonstrated in flight, and a span of 28 days will be demonstrated in the near future. Seals and gaskets do not appear to create any problem. For the 22-day demonstration, there was no significant pressure drop; and the start and shutdown characteristics were normal. A relubrication kit will be added to the propulsion system to lubricate the turbine gas box for the long-duration mission.

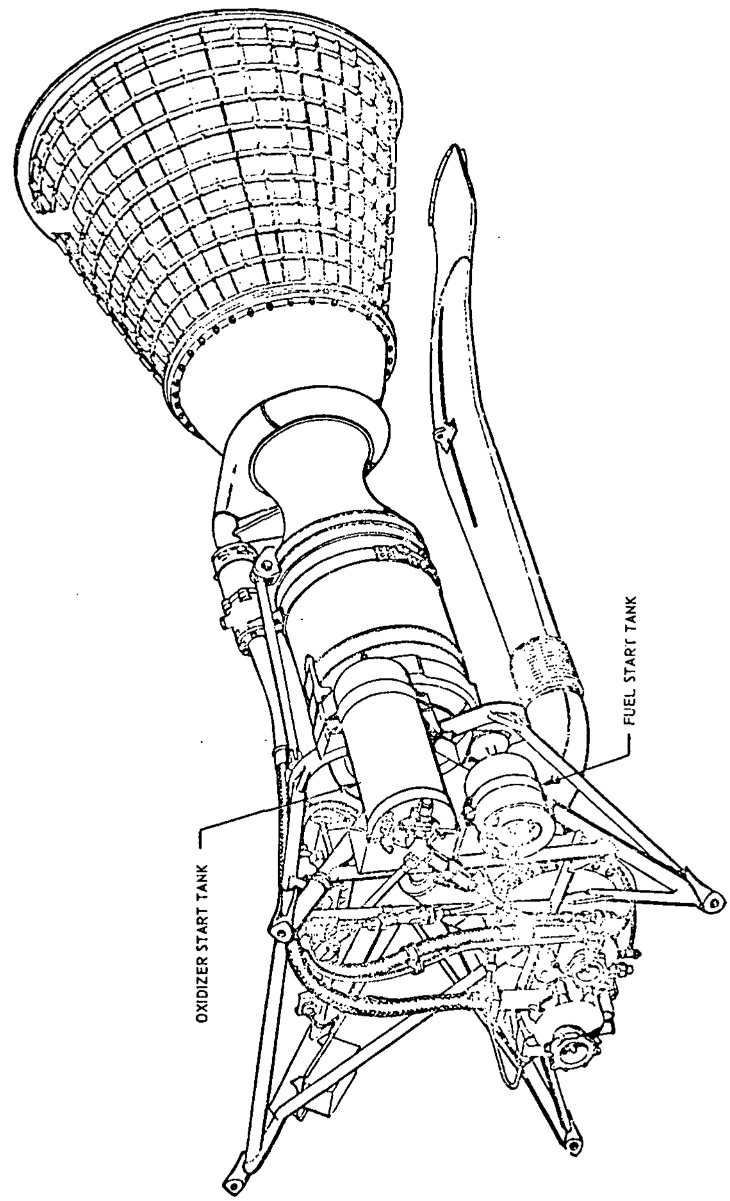


Fig. 5-7 Optional Model 8247 Multistart Engine

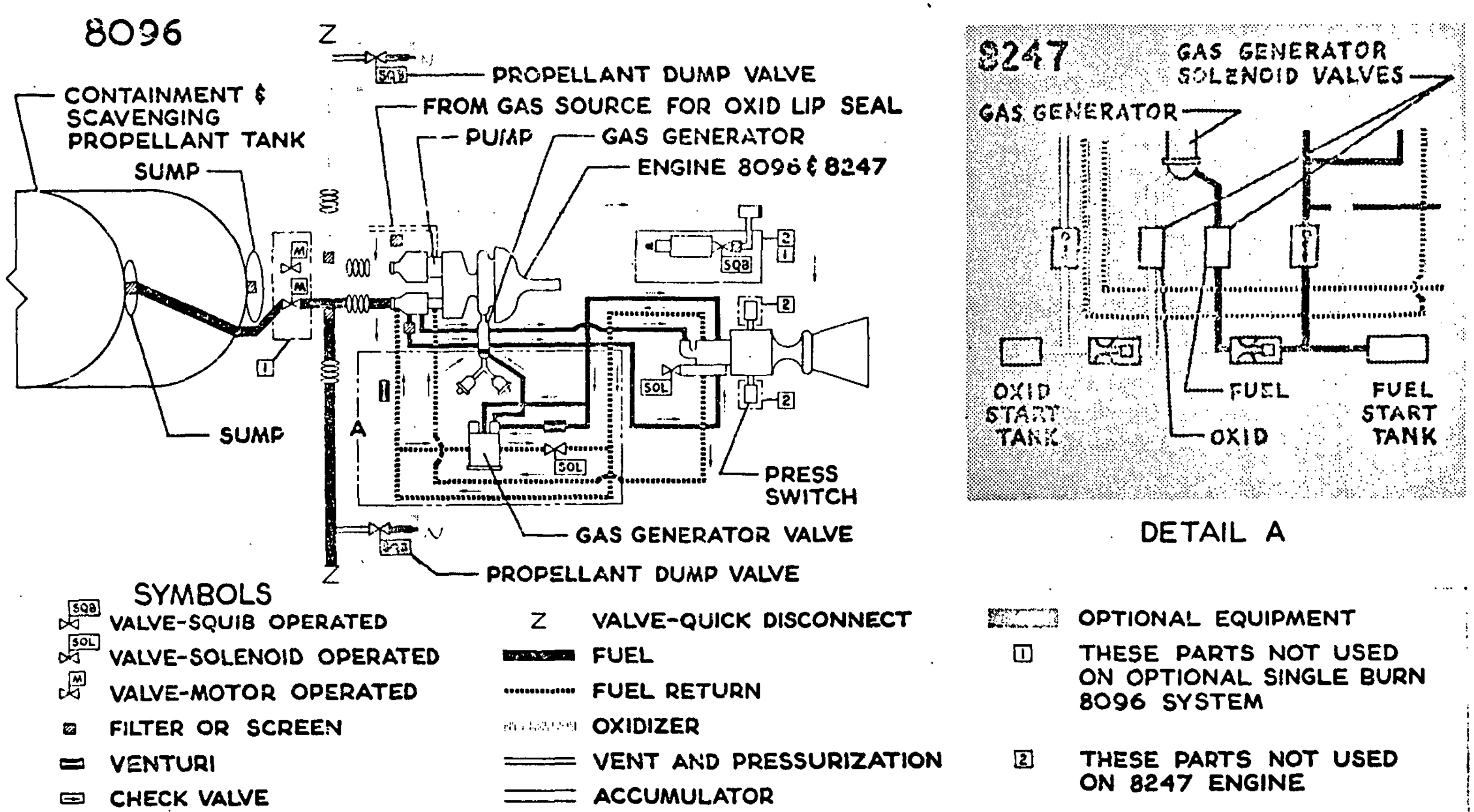


Fig. 5-8 Propulsion System Schematic for Model 8096 and 8247 Engines

5.2.4 Propellant Dump

Mission-abort requirements and safety procedures will require the capability to dump the Agena propellants. Propellant dumping must be possible on the launch pad, during ascent flight, on orbit, and during the initial phase of descending flight. For this study, however, only dumping on the launch pad and after the 50 x 100 nm orbit has been achieved is considered.

The present propulsion system includes capability to dump residual propellants and pressure gas through special dump valves, as shown in Fig. 5-6. These dump valves are small, and dumping the entire load of propellant would require considerable time. For the abort dumping application, therefore, it is recommended that the propellants be dumped through the fill lines. This approach requires new control valves to be installed. After loading the Agena into the orbiter cargo bay, these fill lines will then be connected to dump lines from the Agena service panel. Figure 5-9 gives a summary of the propellant dump times required for the various operational conditions and dump systems. Using the existing fill lines and sequential dumping would require a total of 14 min to dump all of the fuel on orbit. This should be sufficient, since one orbital pass is on the order of 87 min. Dump time could be reduced further by (1) simultaneous dumping of fuel and oxidizer, (2) by increasing the dimensions of the fill lines, or (3) by running the engine pump system. Options (2) and (3) would require additional modifications to the plumbing.

Dumping of the propellant on the launch pad when the booster/orbiter is in the vertical position will require a total of 8 min. If, however, a requirement is established that the propellant be dumped with the Agena in a horizontal position, it may be necessary to add additional dump lines from the side of the tanks in order to drain all of the fuel.

Pressurization system modifications will also be required to regulate tank pressure during the dumping process. After the dumping is completed, it may be desirable to close the dump valves and repressurize the tanks to approximately 5 psi to maintain structural strength. This can be done by using the onboard nitrogen supply, since this gas will not be needed if the mission is aborted. This approach will require additional plumbing and valves to connect the nitrogen bottles to the pressurization system.

VEHICLE OPERATION	VEHICLE CONDITION	DUMP TIME – MIN. (O)/(F)				
		EXISTING DUMP HARDWARE	EXISTING FILL LINES	ENGINE PUMP SYSTEM	NEW DUMP LINES	TANK SIDE NEW DUMP LINES
PROPELLANT LOADING	VERTICAL	76/39	8/5	4/4	–	–
STORAGE (14 DAYS)	VERTICAL	76/39	8/5	4/4	–	–
MATED WITH ORBITER	HORIZONTAL	1/2 DUMP	1/2 DUMP	1/2 DUMP	1-3/0.5-1.5	7/7
ON PAD	VERTICAL	76/39	8/5	4/4	1-3/0.5-1.5	–
ON ORBIT	*0 g	76/39	9/5	4/4	–	–

*WITH SHUTTLE SUPPLIED THRUST VECTOR

Fig. 5-9 Dump Considerations

5.2.5 Agena Tanking

It is presently anticipated that the Agena will be tanked prior to installation in the orbiter cargo bay. This tanking may take place up to 2 weeks prior to installation of the Agena in the cargo bay. The actual tanking process will be performed with the Agena in a vertical position and mounted to the adapter. After the tanking is completed, the Agena may be rotated to a horizontal position and stored until installation in the orbiter cargo bay. No specific modification to the Agena hardware is expected for this procedure; however, new techniques and sequences for ensuring a dry engine must be developed.

5.3 GUIDANCE AND CONTROL

The inertial ascent guidance system (AGS) that was developed for the Ascent Agena vehicle has sufficient capability and flexibility to be used also as the guidance system for the Agena tug application. Some hardware modifications will be required, and additional equipment will be needed to augment capability and to provide compatibility with the shuttle system.

The Agena guidance and control subsystem consists of an inertial sensor assembly (ISA), a guidance computer (GC), flight control electronics (FCE), hydraulic actuators for thrust vector control, and a pneumatic system for attitude control during coast phases and on-orbit attitude stabilization. A block diagram of the basic system is shown in Fig. 5-10. Additional equipment is indicated by dashed lines; existing equipment that is not needed is crossed out. For certain missions, a command receiver will be added so that the guidance constants and parameters can be fed to the computer during flight if desired. Also, since the guidance computer will be used for checkout and monitoring both prior to and after deployment from the orbiter, various sensors and checkout equipment must be added.

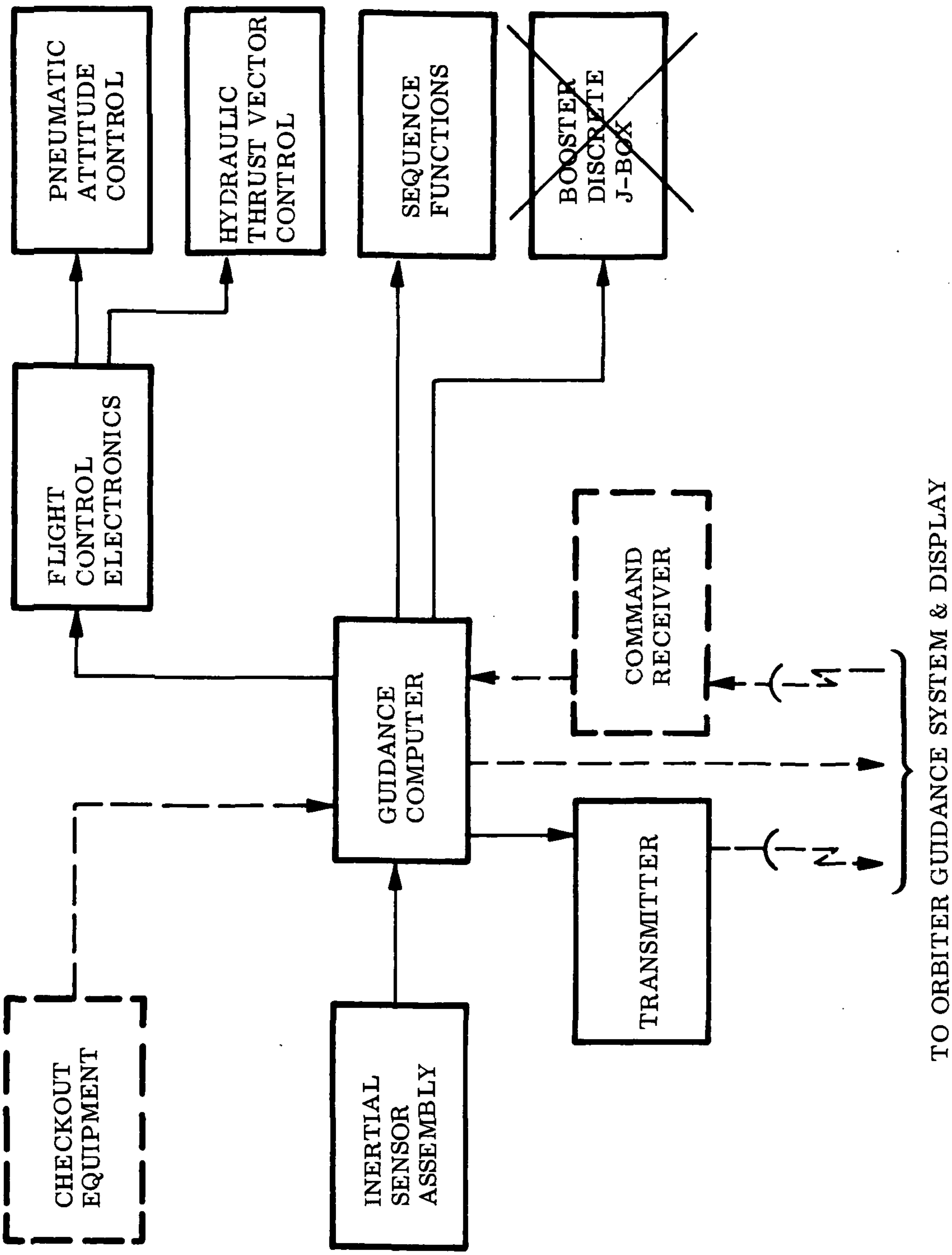


Fig. 5-10 Agena Inertial Guidance System

5.3.1 Short-Duration Missions

For all short-duration missions, such as injection of interplanetary probes and placing satellites into orbits, including synchronous-equatorial missions, the inertial guidance system shown in Fig. 5-10 will perform the task with a high degree of accuracy.

5.3.2 Long-Duration Mission

For a long-duration mission, such as the sun-synchronous mission with 30 days stay-time under active attitude control, it will be necessary to augment the inertial guidance system with sensors to compensate for gyro drift. The systems discussed below are candidates for this task.

One method would be to include the complete dual attitude control system (DACS) in its present form to augment the AGS system. The DACS consists of a velocity control assembly, sequence timer, gyro reference assembly, augmented electronic assembly, and horizon sensor assembly. In this case, control of the vehicle will be transferred from the AGS to the DACS system after the spacecraft orbit has been established. The guidance computer and the inertial sensor assembly can then be turned off until just prior to the final orbit maneuvers. This combined system is shown schematically in Fig. 5-11; however, the velocity control assembly and the sequence timer have been removed from the DACS since they are not needed for this application.

Another method would be to add only the horizon sensor unit from the DACS system. Output from the horizon sensor would then be fed to the guidance computer, together with the output from the inertial sensor assembly. This would represent a saving in control system weight of approximately 100 lb, but it has the disadvantage that the inertial sensor assembly and the guidance computer must run continuously for 30 days. Also, since the power consumption will be high, the additional power supply weight may offset any gain from eliminating the DACS.

A third method would be to use only the horizon sensor unit for attitude control and feed the output directly to the flight control electronics. This will require additional electronic equipment between the horizon sensor assembly and the electronics assembly,

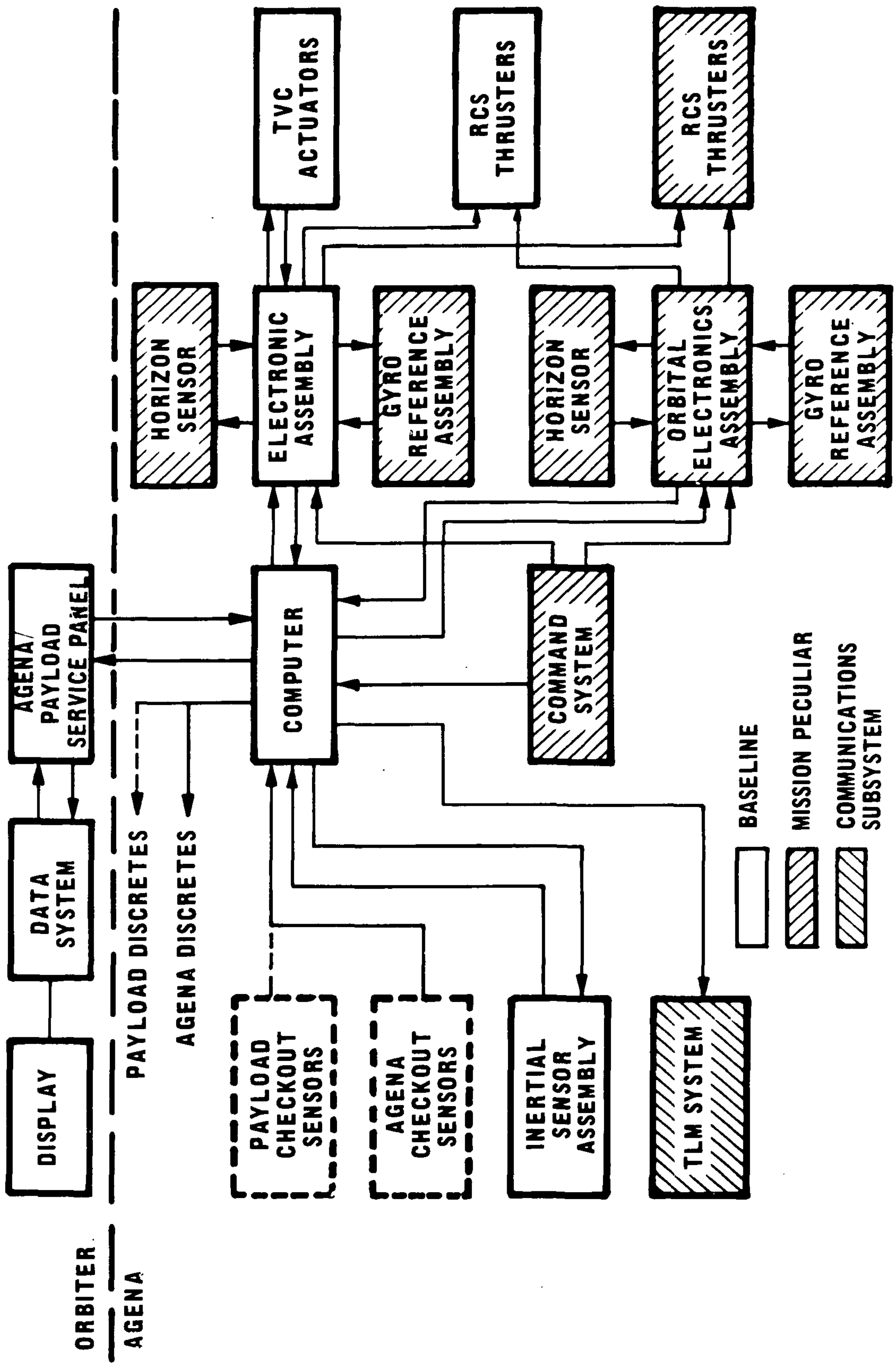


Fig. 5-11 Guidance and Attitude Control System

but it has the advantage that the main guidance components can be turned off for long orbit stay-times, which will significantly reduce power requirements and increase the reliability of the guidance system.

5.3.3 Alignment

The Agena guidance system will be aligned independently from the shuttle guidance system; procedures similar to those currently employed with expendable booster flights will be used. No modifications are required in the Agena guidance system, although GSE for precise azimuth alignment may be required for missions requiring accuracy better than that available by gyrocompassing.

5.3.4 Checkout Equipment

To support system checkout and to monitor the vehicle performance and safety during flight, a number of diagnostic sensors will be included. Sensor output will be checked by the guidance computer and the information stored so that the time history of a given parameter can be reconstructed if desirable. A preliminary list of sensors is given below:

- Fuel tank pressure
- Oxidizer tank pressure
- Fuel tank/oxidizer tank differential pressure
- Fuel tank temperature
- Oxidizer tank temperature
- Helium tank pressure
- Helium tank temperature
- N_2 tank pressure*
- N_2 tank temperature*
- Fuel/oxidizer leak detectors
- Oxidizer pump inlet temperature*
- Oxidizer pump inlet pressure*
- Thrust chamber pressure*
- Turbine speed counter*
- N_2 gas valve temperature*
- Hydraulic oil pressure*
- IAS input voltage and current
- Computer voltage and current
- Main bus voltage and current
- Gyro bus voltage and current
- Gyro temperatures
- Accelerometer data output (prelaunch and deployment)
- Fuel pump inlet pressure

*Included in Agena as standard equipment

5.4 COMMUNICATIONS

The communication subsystem used in the Ascent Agena is not compatible with the NASA system and the shuttle equipment. Therfore, replacement of the present equipment with a system as shown in Fig. 5-12 is proposed. This system, which operates on unified S-band, provides both data transmission and tracking information for ground operation.

A command decoder added as mission-peculiar equipment will provide the capability to update the guidance system and turn equipment on and off. This unit will be needed only for the long-duration missions; however, since it weighs only a few pounds it would be advantageous to include this capability as standard equipment.

5.5 ELECTRICAL POWER

The electrical system is a simple, unregulated 28 VDC system powered by silver-zinc batteries. Each Agena subsystem has self-contained power supplies to provide maximum overall system reliability and electromagnetic interference (EMI) isolation. Electrical power for pyrotechnics is supplied from a pyrotechnic battery with diode isolation from the main electric bus, which isolates pyro surges from the main electrical bus but allows the pyro battery to provide power also to the main electrical system.

5.5.1 Power Supply

On the launch pad and during ascent flight to shuttle orbit, the Agena will receive electrical power from the orbiter power supply system through an umbilical connection. The Agena operates on a 28 VDC system; the shuttle delivers regulated 34 VDC nominal power with a regulation range of 30 to 40 volts. A power-conditioning unit is therefore required to make the two systems compatible. It is assumed that this unit will be located in the Agena service panel in the orbiter cargo bay and will therefore be a nonrecurring item chargeable to the Agena system weight. A basic block diagram of the power supply and distribution system is shown in Fig. 5-13.

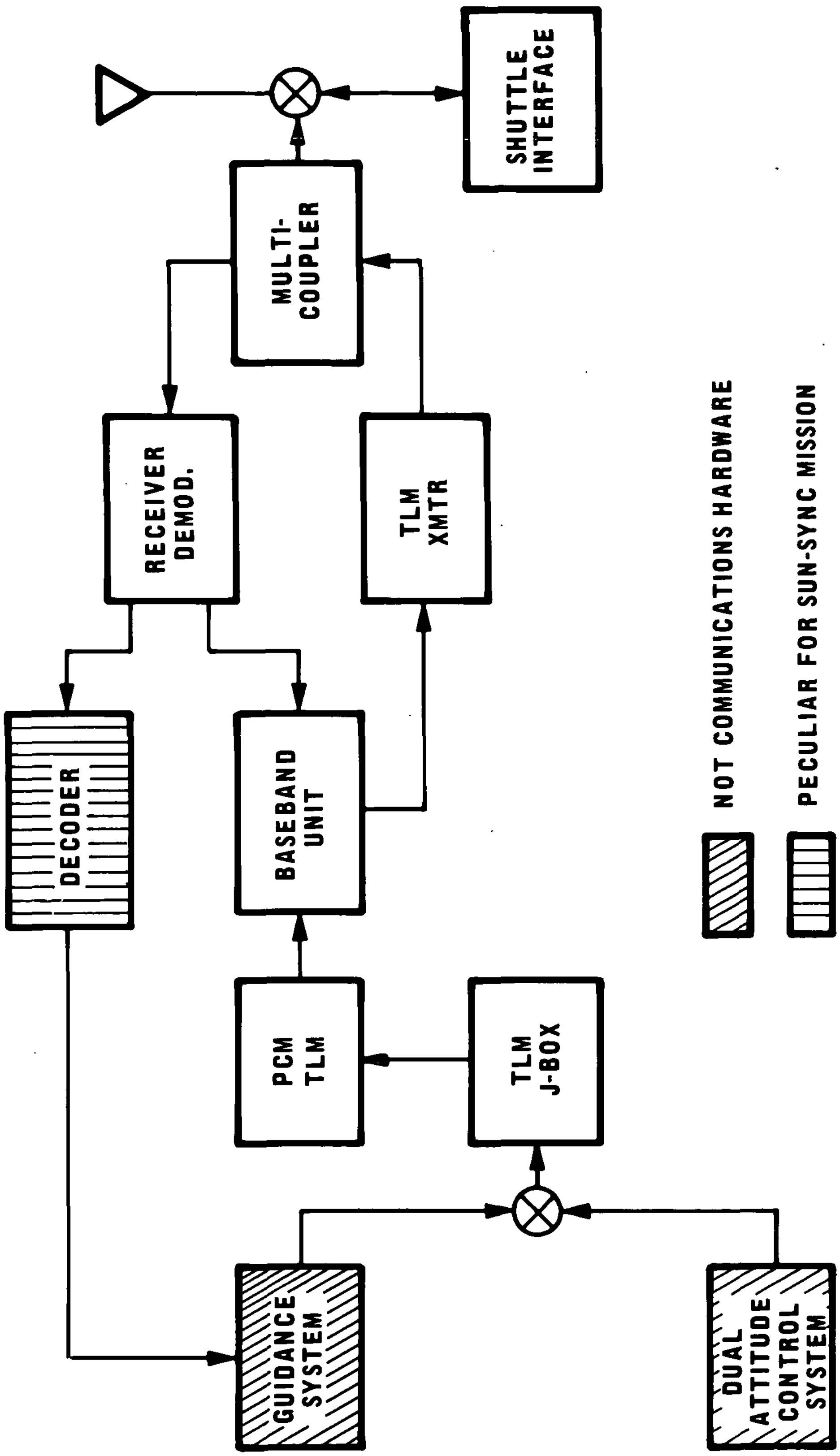


Fig. 5-12 Communication System

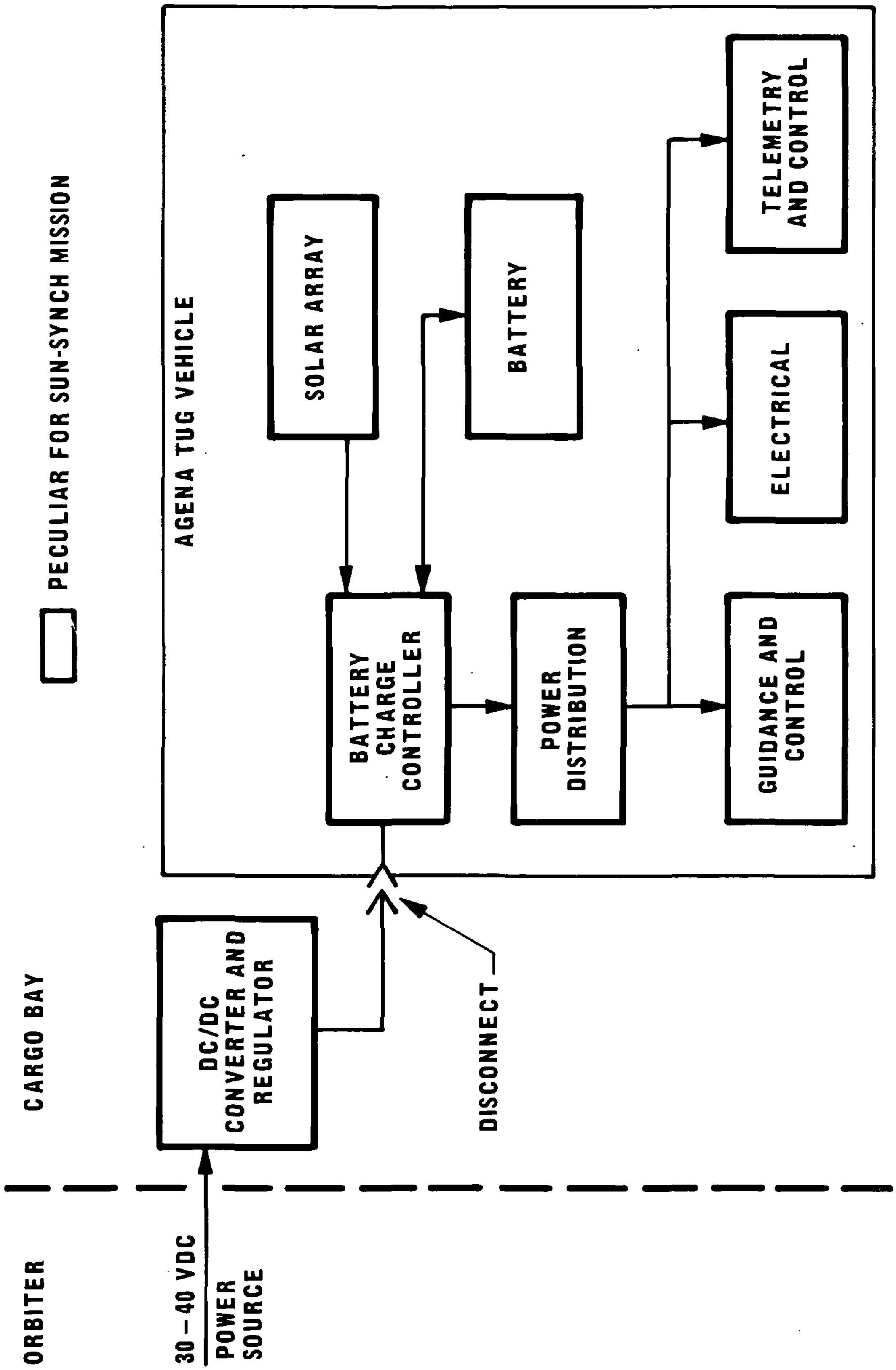


Fig. 5-13 Electrical Power System

For short-duration missions (less than 24 hr), a number of silver-zinc primary batteries of different capacity are available that can supply sufficient power to the Agena. A power profile must be established and the total power requirement evaluated for each mission. This power profile must start from the Agena deployment on shuttle orbit and run until the mission is completed. Once the power demand is determined, a suitable battery or combination of batteries can be selected that will provide sufficient power for the mission. Battery weights of about 0.0107 lb/w-hr are typical.

For long-duration missions such as the sun-synchronous mission with 30 days stay-time, solar panels combined with rechargeable nickel-cadmium secondary batteries offer attractive solutions. Two types of flight-qualified solar array leaf assemblies are presently available; the choice depends primarily on the desired power characteristics. For the sun-synchronous mission, it may be possible to attach the panels directly to the side of the Agena that will be oriented toward the sun during the orbital stay-time, thereby avoiding folding-mechanism and sun-tracking complexities.

Several types of secondary batteries are also available to be used in connection with the solar arrays. Selection of the battery configuration will depend on the power requirements of the Agena and the attached payload.

5.5.2 Power Distribution

A basic block diagram of the power distribution system for the Ascent Agena is shown in Fig. 5-14. For the tug application, the power distribution will be basically the same; however, some new equipment must be added and some equipment that is not needed can be removed. The components that can be removed (shaded in Fig. 5-14) are as follows:

- a. Command Destruct System
  - (1) Command destruct antenna
  - (2) Command destruct module
  - (3) Command destruct unit
- b. Ascent Telemetry
  - (1) C-band beacon transponder
  - (2) Ascent antennas

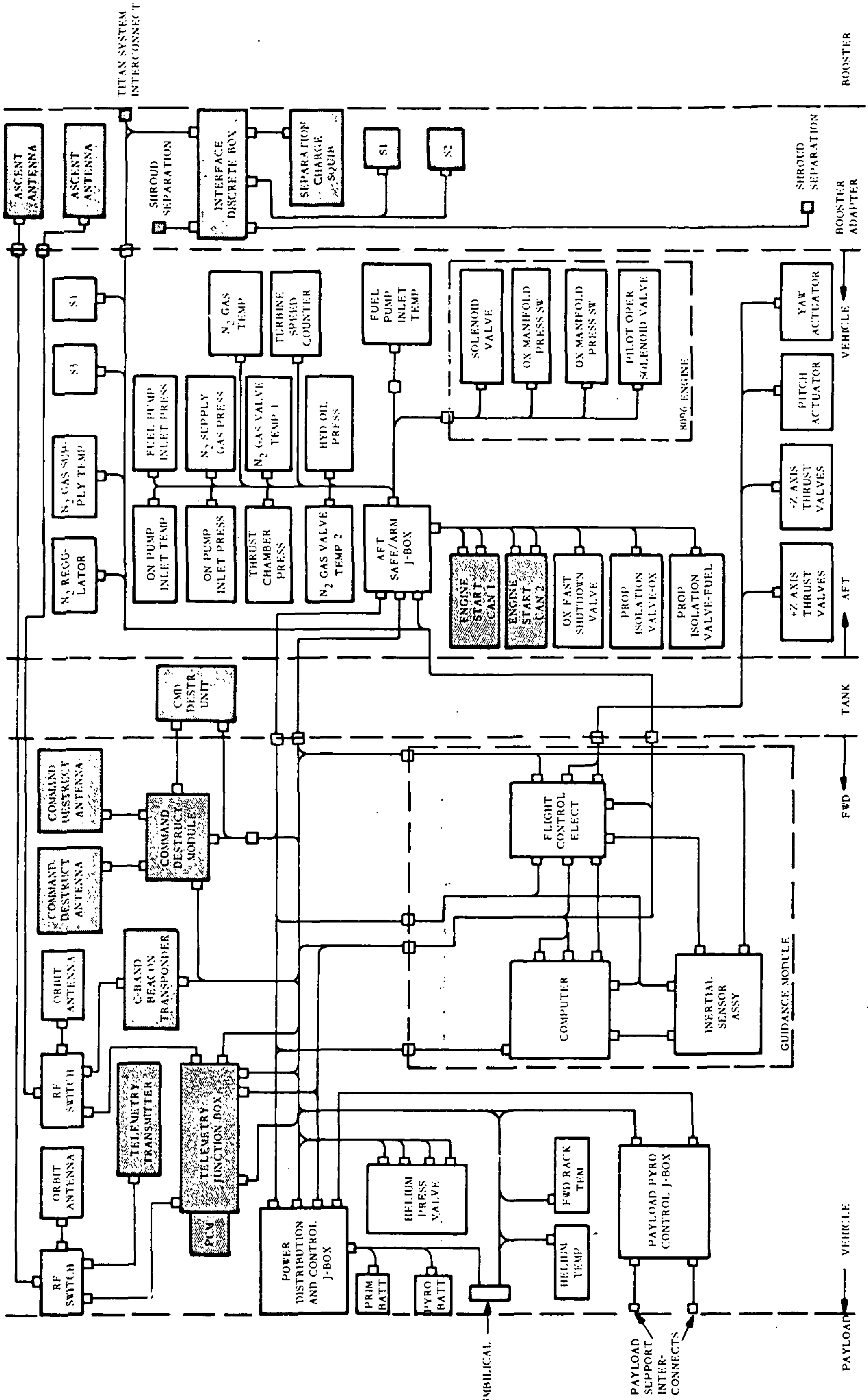


Fig. 5-14 Ascent Agena Power Distribution System

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c. Booster Interface Equipment

(1) Interface descrete box

(2) Separation charge squib

(3) Self-destruct switches S1 and S2

(4) Booster system

d. Fairing Separation. Shroud separation charges.

e. Engine Start System. The wiring to the engine start system must be changed. Instead of the two start cans operated by squibs, there will be two electrically operated start valves that will allow the propellants to flow into the gas generator from the rechargeable start tanks.

f. Communication System. The present communication equipment will be removed and replaced by other units that will require a different wiring.

Section 6
OPERATIONAL SCHEDULES

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OPERATIONAL SCHEDULES

The Agena prelaunch operations and schedule spans can be accomplished independently of shuttle operations and schedules, as shown in Fig. 6-1, up to mating of the Agena/payload combination with the orbiter.

The following schedules present the Agena sequence of events from vehicle final assembly in the factory through shuttle liftoff. The interrelationships between shuttle and Agena operations are presented wherever applicable.

6.1 AGENA/SHUTTLE OPERATIONAL FLOW

Figure 6-2 is a flow diagram of the complete Agena sequence of events. Related shuttle and payload operations are depicted with dashed-line boxes. Note that there can be up to a 14-day storage span between loading of Agena propellants and gases and installation of the Agena in the orbiter cargo bay.

6.2 FACTORY-TO-LAUNCH-SITE OPERATION

The spans shown in Fig. 6-3 for "Agena Final Assembly" and "Agena Systems Test" are standard spans from an existing Agena program. They could easily be shortened, if desirable. DD-250 signoff would occur just prior to shipment to the launch base.

6.3 AGENA PRELAUNCH OPERATIONS

The Agena prelaunch phase indicated in Fig. 6-4 includes all launch base operations up to installation in the orbiter cargo bay. The major pre-orbiter mate operations are shown in Fig. 6-5. Agena propellants and gases will be loaded after payload mate and interface compatibility checks with a shuttle simulator have been completed. The loaded Agena can be stored for up to 2 weeks prior to being mated with the orbiter.

The shuttle simulation will permit complete verification of all Agena and payload interfaces. Typical examples of these interfaces are (1) pin-to-pin interconnect verification checks, (2) fit and alignment, (3) data stream and format compatibility, and (4) orbiter data display and control at the Agena specialist station.

6.4 AGENA/SHUTTLE LAUNCH OPERATIONS

After being mated with the orbiter, the Agena and payload will impose minimum constraints on orbiter prelaunch operations. The Agena launch-readiness checks are much lower level tests than those performed during prelaunch operations. The launch-readiness checks may be the same as the predeployment checks performed in orbit. No hookup to the Agena, other than the already-installed flight hookup, is needed for this test.

If the guidance optical alignment is required, it will be performed at approximately T-30 minutes in the terminal countdown. After completion of the optical alignment, no further Agena checks are required until initiation of the on-orbit predeployment checks.

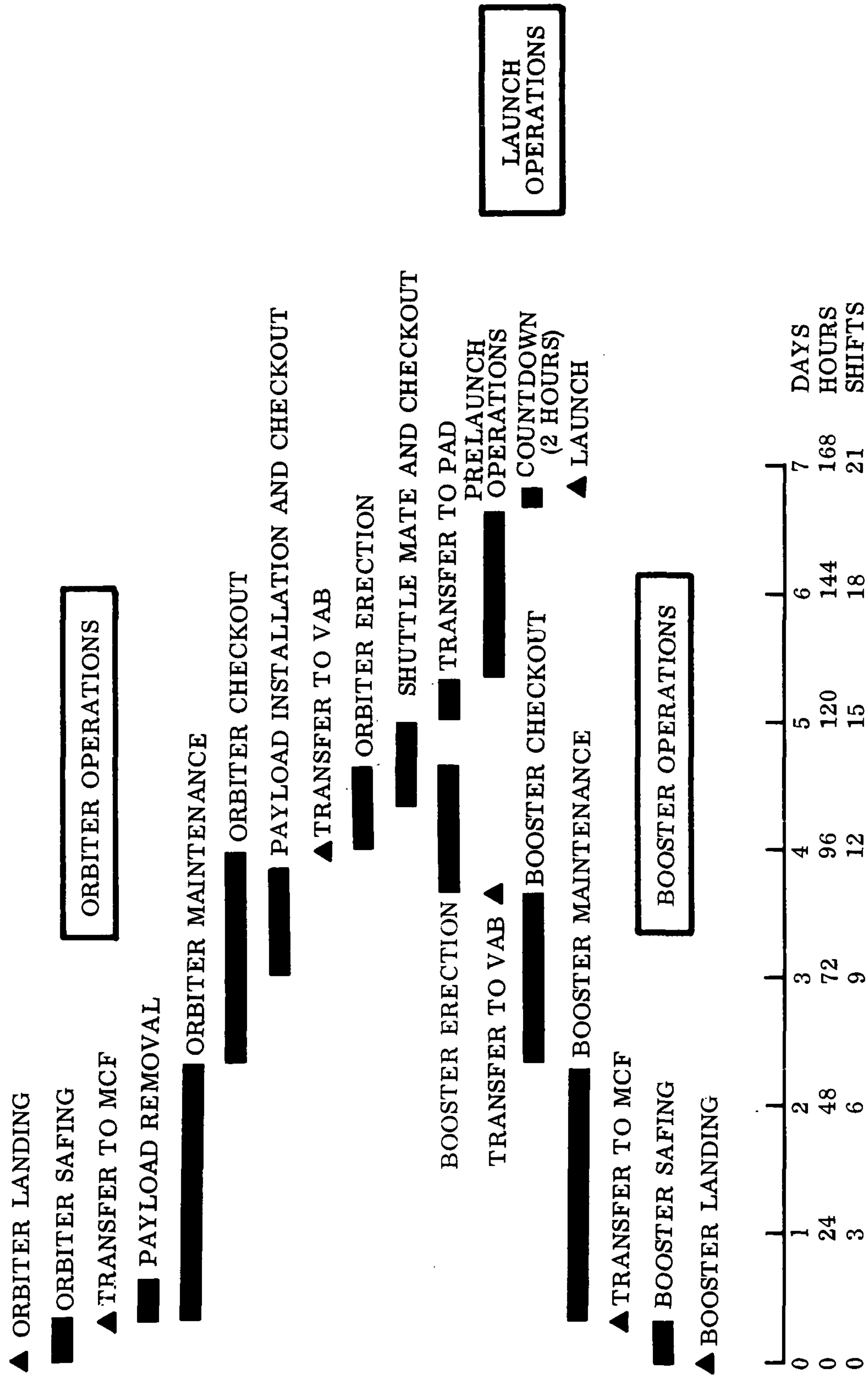


Fig. 6-1 Space Shuttle Ground Operations Timeline

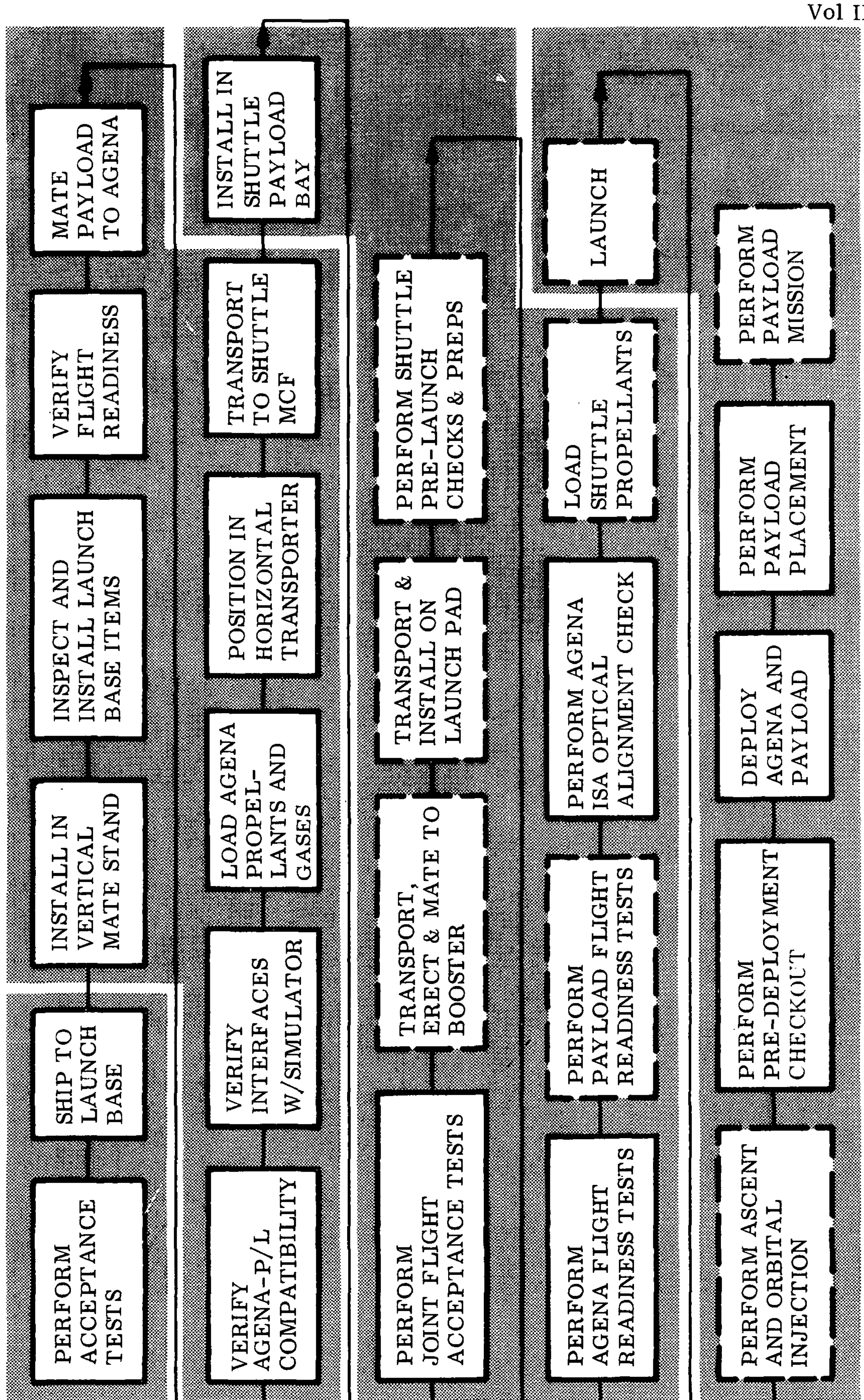


Fig. 6-2 Agena/Shuttle Operational Flow Diagram

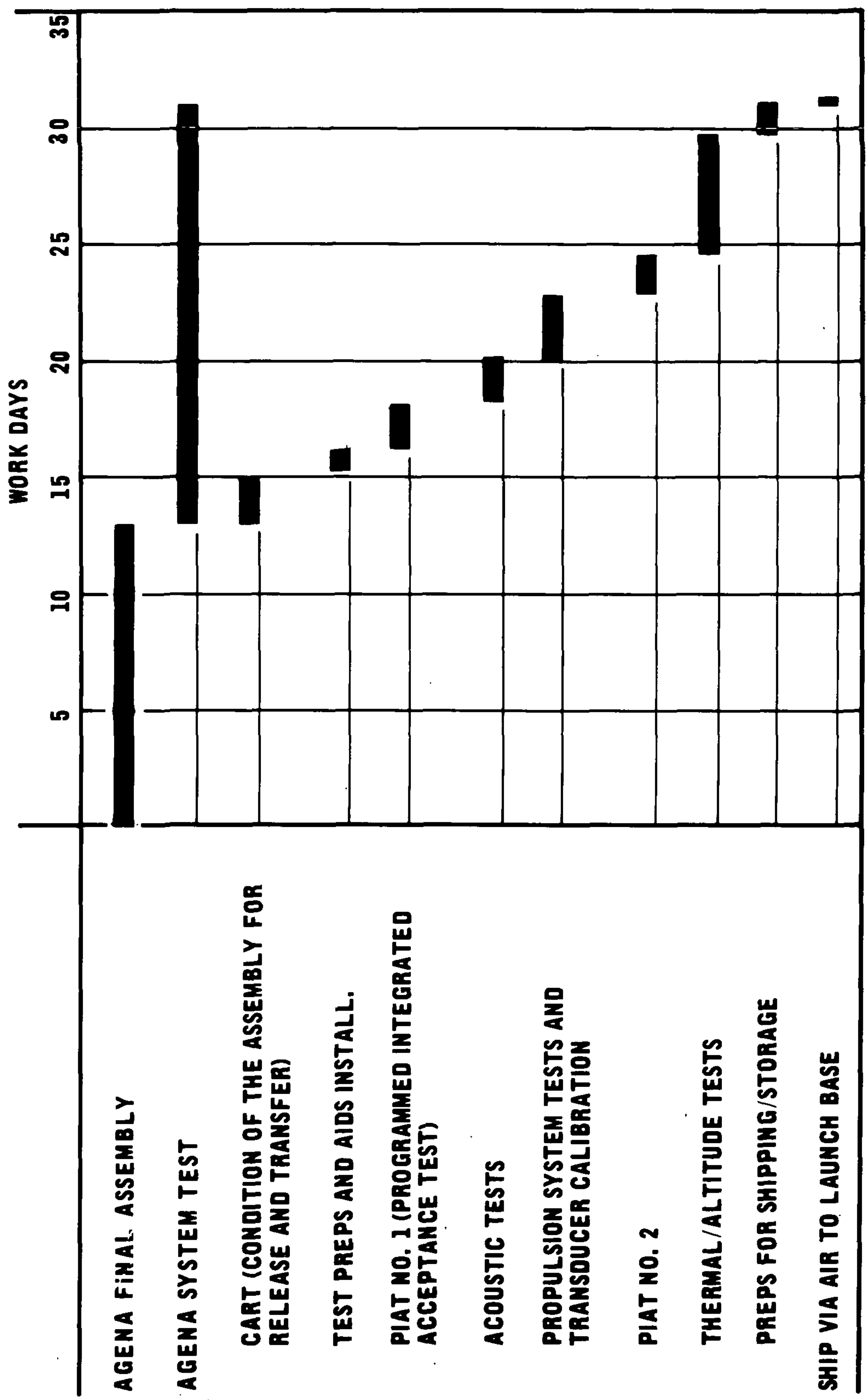
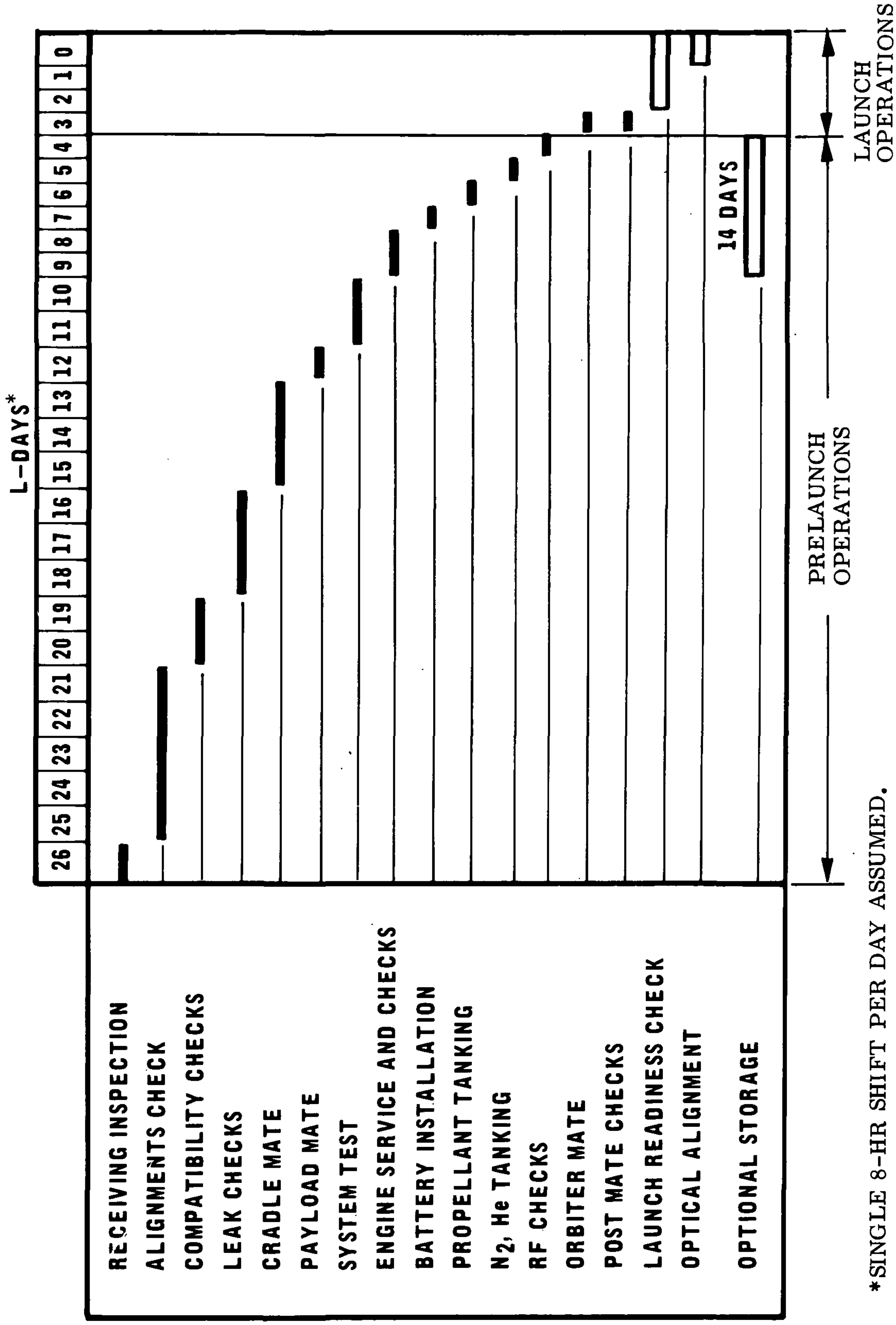


Fig. 6-3 Factory-to-Launch Site Operations



*SINGLE 8-HR SHIFT PER DAY ASSUMED.

Fig. 6-4 Milestone Schedule

SHUTTLE PAYLOAD PROCESSING FACILITY

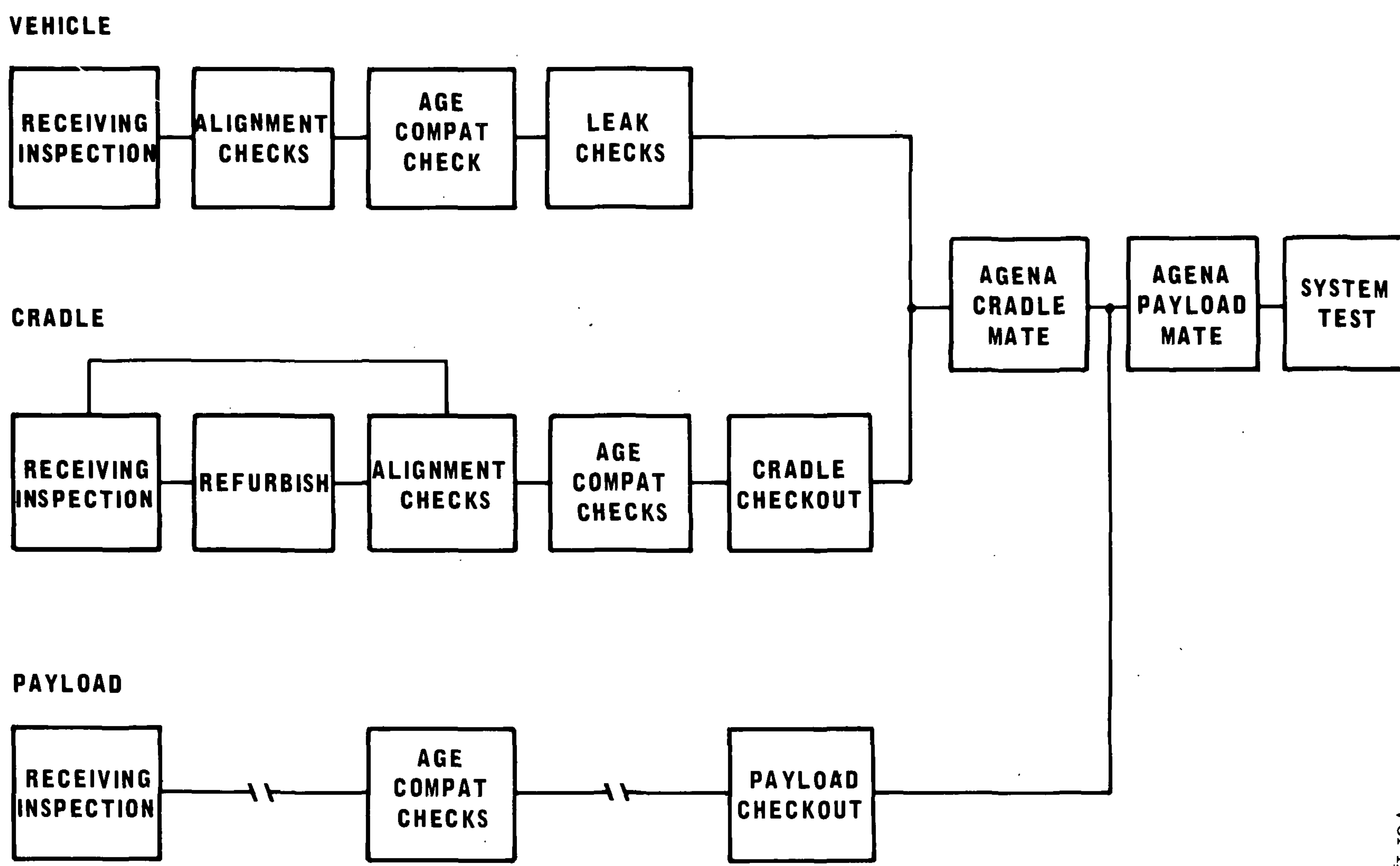


Fig. 6-5 Agena/Payload Pre-Orbiter Mate Operations

LMSC

SPACE SYSTEMS DIVISION

LOCKHEED MISSILES & SPACE COMPANY, INC.

A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA